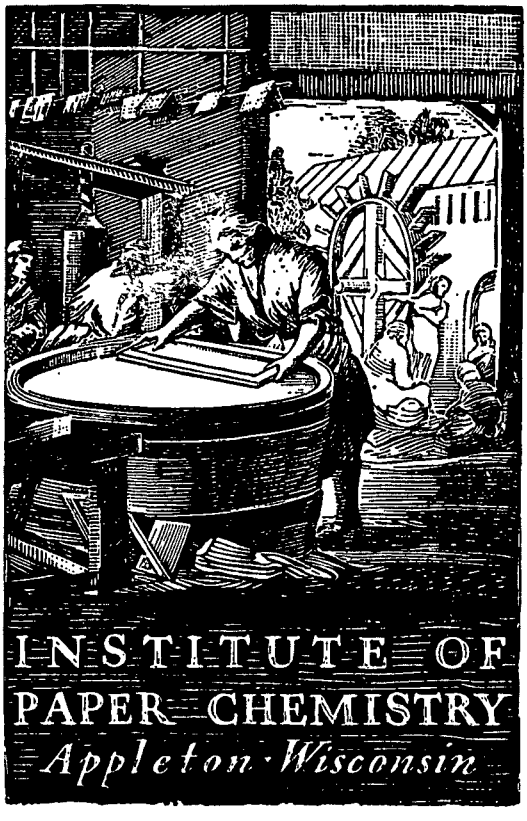

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Two

A Progress Report

to

MEMBERS OF GROUP PROJECT 3212

February 14, 1975

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Two

A Progress Report

to

MEMBERS OF GROUP PROJECT 3212

February 14, 1975

MEMBERS OF GROUP PROJECT 3212

Abitibi Paper Company Ltd.

Blandin Paper Company

The Mead Corporation

The Procter & Gamble Company

Scott Paper Company

Weyerhaeuser Company

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

SUMMARY

The first report for this project covered bark characterization information for quaking aspen, sugar maple, white birch and northern red oak. This report presents the same type of information on loblolly and slash pine, Douglas-fir and western hemlock.

Loblolly pine has a wood specific gravity of 0.45 and an average bark specific gravity of 0.33. Bark extractives levels averaged 8.5%. Morphologically, the bark contains large numbers of sieve cells, some stone (sclerified phellem) cells but no fiber. Pulping loblolly pine gave a solids yield of 20-28%. Screening of the bark pulp resulted in 60-70% of the solids passing through the 100-mesh screen. The fraction retained on the 60- and 100-mesh screens contained 6 grams of sieve cells, 1 gram of stone (sclerified phellem) cells and 1 gram of parenchyma and peridermal cells per 100 grams of bark pulped. It appears that segregation of loblolly pine wood and bark chips could be accomplished by several methods. Compression debarking and use of the Cartesian Diver technique are effective in segregating bark and wood chips but have the disadvantages of being fairly complicated to use and producing wet rejects that are less useful as fuel. Screening, hammermilling and rescreening fractions high in bark is an inexpensive, quick way to upgrade chip mixture quality and could be used in conjunction with other segregation techniques if necessary.

Slash pine, based upon values in the literature and measurement data from trees sampled as part of the project, has an average wood specific gravity of 0.54 and a bark specific gravity of 0.35. Extractives levels were 3.3 and

8.4% for the wood and bark of slash pine. Pulping slash pine bark produced a solids yield of approximately 24% and, of this, approximately 6% were sieve cells and 2% were stone (sclerified phellem) cells. There was no fiber produced. Compression debarking, possibly used in combination with hammermilling and/or screening, also has possibilities for separation and segregation of wood/bark chip mixtures of slash pine. Water flotation techniques also appear more useful for slash pine than loblolly pine, due to shorter segregation times involved.

Douglas-fir was found to have a wood specific gravity of 0.43 and a bark specific gravity of 0.41. Extractives levels were 4.0 and 16.4% for the wood and bark of Douglas-fir. Morphologically, Douglas-fir does contain some sclereidlike fibers which would act primarily as filler material in paper. Douglas-fir bark, when pulped, had a solids yield of 17-18%. When screened, 10% of the solids were retained on the 60- and 100-mesh screens, including 5% sclereids fibers, 2% schlereids, and 3% sieve cells. Compression debarking is worthy of consideration in segregation of wood and bark chips of Douglas-fir, achieving 92% wood recovery with 8% bark contamination. The screening — hammermilling — rescreening approach also has merit and it is possible that improvements in screening would result in even better segregation.

Western hemlock had a wood specific gravity of 0.40 and an average bark specific gravity of 0.45. Bark extractives levels averaged 11.7%. Morphologically, the bark contained large numbers of sieve cells and sclereids. The sclereids are of a type that could cause "fish eye" type problems in some paper grades. Sieve cells would act mainly as filler material and possibly as a bonding material. There are no fibers present in the bark of western hemlock. Pulping western hemlock bark gave a solids yield of approximately 36%. Screening the pulp resulted in 13% sieve cells and 11% sclereids remaining on the 60- and

100-mesh screens. Another possible method of handling the bark problem would be through compression debarking (92% wood recovery with 4% bark contamination). As with other species investigated in this report, screening chip mixtures, hammer-milling the fractions high in bark and rescreening is worthy of further consideration. Simple water flotation techniques appear of little value for this species due to similarities in wood and bark specific gravity and basic density at various moisture contents.

INTRODUCTION

Improved utilization through whole tree chipping requires efficient methods of handling bark problems. As more becomes known about species-to-species and tree-to-tree bark variation, it becomes clear that a "single solution" to the bark problem is not possible. The major objective of this project is to provide interested companies with a concise package of data on the more important pulpwood species in the United States. Such data hopefully will allow appropriate solutions to be made for specific bark problems.

The rapidly changing environmental and energy outlook has made the use of basic data to solve a specific problem a more and more realistic approach. Several years ago, for example, bark contamination in a wood supply was considered excessive if it exceeded 3% while wood losses likewise were excessive if they exceeded 5%. These criteria have been changing rapidly as the result of improved pulp cleaning techniques and because of the high value of wood and bark as fuel. Approaches that were considered to be of limited value because of high wood loss are being reconsidered because of the usefulness of the recovered bark and wood as fuel. Additional changes in the criteria for judging bark segregation procedures can be expected.

In an effort to make the information as useful as possible, the format for each report and for each species is exactly the same. Use of such a procedure results in some repetition but makes each species report a study in itself and not dependent upon other reports.

Progress Report One provided cooperating companies with information on the bark characteristics of quaking aspen, sugar maple, white birch, and

northern red oak. The report that follows presents information on the fundamental properties of the bark of loblolly pine, slash pine, Douglas-fir, and western hemlock. The information was obtained from a comprehensive literature search combined with measurement data taken on a limited number of representative pulpwood-sized trees of each species.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development was covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1) illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

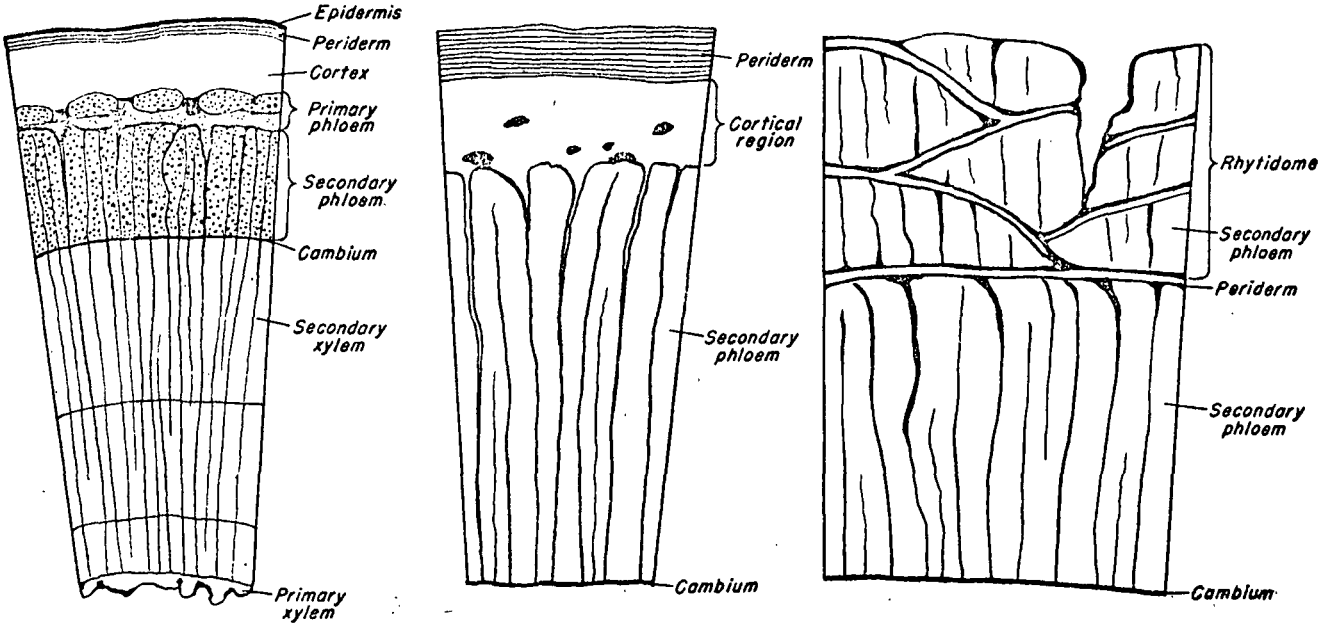

Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch or Stem. (2) Cross Section of Bark Having Persistent Cortex, such as that in the Middle-Aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53 and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later morphological examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro

Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(c \cdot d)/[c-(b-a)]$ where:

a = weight of pycnometer + heptane

b = weight of pycnometer + heptane + chip

c = weight of chip (wet — before being placed in heptane)

d = density of heptane.

BARK AND WOOD PROPERTIES OF LOBLOLLY PINE (Pinus taeda L.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Loblolly pine, the principal commercial pine species in the southeastern United States, has a wide range extending from Delaware and central Maryland south to central Florida and west to eastern Texas. This range comprises two main physiographic regions, the Coastal Plain and the Piedmont. Only in the Mississippi River bottom lands is this species absent.

In the loblolly pine range, some climatic conditions are specific and others are highly variable. The climate is humid with long hot summers and mild winters. The northern extension of this species is probably limited by temperature, and the western extension by precipitation. Elevations vary greatly from sea level to over 2000 ft, but growth seems to be less affected by altitudes than by soil differences. A wide variety of soils support the growth of this species, but loblolly grows best on soils with poor surface drainage, a deep surface layer, and a firm subsoil. With advanced age, individual trees may attain a diameter of 50-60 inches and a height of 150 ft. Where moisture is comparatively plentiful, pure loblolly stands are widespread.

WOOD AND BARK MORPHOLOGY

Wood

Wood features of loblolly pine are similar to those of the other southern yellow pines. Hard and moderately heavy to heavy, the sapwood appears nearly white to pale yellow with a heartwood ranging from yellow to orange to light brown. Up to the age of 50 years, most of the volume is light-colored sapwood, as southern pines commonly have little heartwood.

Growth rings are quite distinct. The transition from earlywood to latewood is very abrupt with a usually wide to very wide earlywood zone in loblolly pine. Rays are very fine and not visible unless they include a horizontal resin canal.

Pinewood consists principally of closely packed, radially aligned longitudinal tracheids, or fibers, resin canals, and horizontal ray elements. The longitudinal tracheids comprise more than 90% of the total wood volume of the southern pine. Varying greatly from tree to tree, loblolly fibers range in length from 1.2-5.9 mm with an average of 4.0 mm in 30-year-old trees (3). Shorter than longitudinal tracheids, strand tracheids occasionally occur outside of the thin-walled parenchyma strands that partially surround the vertical resin canals. Longitudinal and horizontal resin canals, lined with thin-walled epithelial cells, interconnect to form a continuous system of resin canals that occupies approximately 0.8% of the total wood volume. Longitudinal canals are larger and more numerous, averaging 90-150 μm in diameter, the horizontal canals, less than 70 μm. Rays, occupying about 9% of the total wood volume of southern pines, are of two types, uniseriate and fusiform, and contain ray parenchyma, epithelial cells, and ray tracheids. These tracheids are distinctive in having complicated and prominent wall thickenings. Ray parenchyma are of two forms, the majority, thin-walled and unpitted, but thick-walled heavily pitted cells do occur which appear lignified. These thick-walled cells increase in number as the sapwood-heartwood boundary approaches.

Bark

The structure of the rough, thick bark among closely related species of southern pine is quite similar although external appearance between individual trees of one species is highly variable. In mature southern pine, the thick,

large-scaled rhytidome generally consists of dark porous tissue subdivided by merging bands of periderms with thin and thick-walled cells. The innermost periderm separates the rhytidome from the inner bark. The much expanded, deformed and loosely arranged secondary phloem tissues in the rhytidome are in great contrast to the phloem in the inner bark. Southern pine barks generally fall in the low to intermediate bark density range.

Bark of loblolly pine is quite variable. Scaly and nearly black in the young tree, it later appears as irregular dark-brownish scaly blocks changing to reddish-brown scaly plates in very old trees. The periderm bands are quite inconspicuous and slate gray. Measuring 0.85-2.0 inches, the comparatively thick loblolly pine bark accounts for approximately 10% of the total log volume. In mature trees, including the trees sampled in this project, the outer bark can account for 85-95% of the total bark thickness by weight. Figure 2 illustrates a cross section of loblolly pine wood and bark. Appendix Table XXVI describes the trees used in this study.

Anatomical Structure of Young Bark

Protection for the young stem is provided by an epidermis consisting of one or more layers of epidermal cells which have a very thick and cutin-free surface. Beneath the epidermis in 2- to 3-year-old twigs, are 2-3 layers of rectangular cells with thickened walls on the outer tangential surface and showing distinct lamellate layers and simple pits on secondary walls. In very young bark, the periderm is composed of mainly thin-walled cells, but quickly develops the alternate layers of thin and thick-walled cells. The cortex consists of regular cortex cells, resin cells and vertical resin canals. Parenchyma, sieve cells, and narrow phloem rays form the inner bark (secondary phloem).

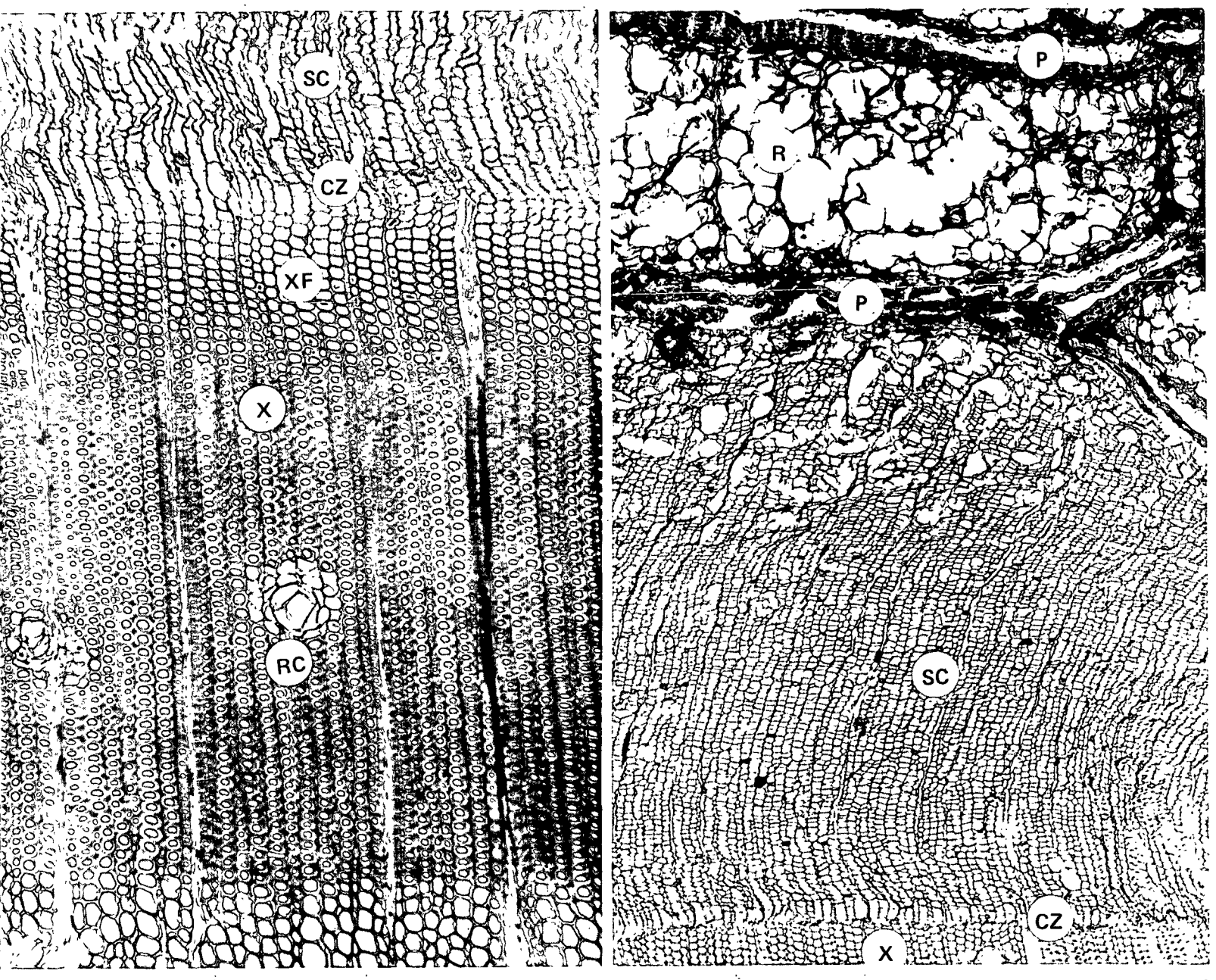

Figure 2. Illustrated is Loblolly Pine Wood (Left) and Bark (Right). The Elements Shown Include the Xylem (X), Resin Canal (RC), Immature Xylem Fibers (XF), Cambium Zone (CZ), Sieve Cells (SC), Periderm (P) Where the Short, Thick-Walled Phellem Cells Are Found and the Outer Bark or Rhytidome (R). The Outer Bark Consists of Alternating Bands of Periderm (P) and Isolated Secondary Phloem. Magnification — 75X for Right-Hand Photo, 45X for Left-Hand Photo

Anatomical Structure of Mature Bark

Composed of dead cells, the outer bark of mature southern pines has alternating layers of distorted phloem cells and periderm bands. Cut off and isolated by the successive periderm formations, these deformed phloem cells are crushed sieve cells and greatly expanded longitudinal parenchyma cells of the secondary phloem. In the inner bark, sieve cells greatly outnumber the parenchyma cells, but in this old isolated phloem tissue, the enormously enlarged parenchyma occupy most of the volume accounting for the porous structure of the outer bark. The periderms, throughout most of their extent, lie in the tangential plane, generally parallel to one another, with the edges curving outward to merge with other periderm layers. Of the 3 bands within each periderm layer, the outer phellem is composed of thin-walled cork cells and thick-walled "stone" cells (sclerified cork cells). Compactly arranged, the suberized cork cells have unpitted cellulose walls and are approximately the same shape as the "mother" phellogen cells. Some of the sclerified phellem cells develop distinct lamellate layers of secondary walls and simple pits, and form the only heavily lignified tissue of southern pine bark. These thick-walled phellem cells occupy 10% or less of the rhytidome samples but they greatly influence density and hardness. Arranged in tangential bands of varying widths, the lignified phellem cells have distinct irregular projections which interlock in coglike fashion with adjacent cells. In the midst of the periderm, the phellogen layer consists of a row of thin-walled meristematic cells which divide tangentially to produce the phellem to the outside and the phelloderm to the inside. Regularly aligned in usually 3-5 layers, phelloderm cells are compact close to the phellogen and loosely arranged and expanded with thinner walls closer to the secondary phloem region. Peridermal cells are rectangular in cross and radial section, and hexagonal, about 50 μm in height, tangentially.

Relatively narrow, the inner bark of southern pines is composed of thin-walled sieve cells, albuminous cells, longitudinal and ray parenchyma and epithelial cells. Sieve cells, comparable to xylem tracheids in size, shape and arrangement, are the only distinctly elongated elements and the most abundant by volume. Radially aligned, these long slender cells have thin, nonlignified cellulosic walls with numerous sieve areas corresponding to tracheid pitting. Dispersed among the sieve cells, thin-walled longitudinal parenchyma occur in vertical strands. Abundant crystals composed of calcium oxalate are found in the lumina of both sieve cells and the longitudinal parenchyma. Continuous with xylem rays, the radial alignment of the mostly uniseriate phloem rays becomes distorted a short distance from the cambium. Composed of albuminous cells, ray parenchyma and epithelial cells, all ray cells in the secondary phloem have thin, primary, unlignified walls. Ray tracheids are absent. Instead, erect structures called albuminous cells form the margins of most rays and are associated physiologically with sieve cells, dying and collapsing simultaneously with them. The horizontal resin canals of the fusiform rays are lined with epithelial cells which sometimes clog the ducts with tylosoids in older phloem.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

Specific Gravity

Table I summarizes the information available on wood and bark of loblolly pine and, whenever possible, information on bark has been separated into inner and outer bark. Specific gravity is most often expressed in terms of ovendry weight over green volume. It should be noted that several of the values in Table I are ovendry weights divided by ovendry volumes.

It appears that two of the trees used in the study of loblolly pine, 3212-31 and 3212-32 are closely related as their age, height, diameter at breast height and specific gravity are almost identical. It is fortunate that for many of the tests another loblolly pine was substituted to give as wide a range of information as possible on the species as a whole.

Great variability in total bark specific gravity has been reported, probably attributable to the degree of expansion of old phloem cells and to varying proportions of phellem stone cells (3). According to Phillips and Schroeder (4), loblolly pine bark from plantation-grown trees has a low specific gravity at ground level which increases during the first 25% of merchantable height. From 25 to 100% of merchantable height, the bark specific gravity exhibits a consistent downward trend.

The specific gravity of the total (inner + outer) bark of loblolly pine is usually lower than that of the wood although, as mentioned in the preceding paragraph, this may vary considerably depending upon the morphology of the particular bark samples. Our limited data show the inner bark to be slightly lower in specific gravity than the outer bark. Overall values suggested for use in species comparisons are 0.45 for wood and 0.29, 0.34, and 0.33 for inner, outer, and total bark.

TABLE I

LOBLOLLY PINE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
				0.303	0.262-0.327	Phillips & Schroeder (Ga.) (4)
				0.282	0.234-0.296	Phillips & Schroeder (S.C.) (4)
			0.36			Fournier & Goulet (5)
				0.43		Fournier & Goulet (5)
0.41 (age 15)						Zobel, et al. (6)
0.43 (age 33)						Zobel, et al. (6)
0.47						Wood Handbook (7)
0.45	0.377-0.540					Christopher & Wahlgren (8)
0.46	dbh-5.0-8.9					Wahlgren & Schumann (9)
0.48	dbh-9.0-14.9					Wahlgren & Schumann (9)
0.47						Wahlgren & Schumann (9)
0.47						Besley (U.S.) (10)
0.47						Isenberg (11)
0.51 (age 30-Coastal)						Einspahr, et al. (12)
0.47 (age 30-Piedmont)						Einspahr, et al. (12)
0.58		0.36	0.40	0.38		
0.34[b]		0.25	0.30	0.28		IPC 3212-31
0.34[b]		0.25	0.30	0.29		IPC 3212-32
			0.32			Renfro (13)
				0.560[a]		Harkin & Rowe (14)
0.54[a]						Isenberg (11)
				0.48[a]		Martin (15)

[a] Ovendry weight/ovendry volume.

[b] Low wood specific gravity value is probably attributable to the young (15 years) age of the tree.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on alcohol-benzene extractives levels of loblolly pinewood but much less is known about bark extractives levels. Table II summarizes existing data and includes two loblolly pine (3212-3 and 3212-32) of different geographic origin.

TABLE II

LOBLOLLY PINE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.8	Max (16)
Wood (green wood)	2.8	Stanley (17)
Wood (earlywood)	4.2	Stanley (17)
Wood (latewood)	2.5	Stanley (17)
Wood (heartwood pulp)	2.0	McGovern & Chidester (18)
Wood (heartwood)	4.1	McGovern & Chidester (18)
Wood	2.9	Byrd, et al. (19)
Wood	2.7	Isenberg (11)
Wood (juvenile)	3.1	Zobel, et al. (6)
Wood (mature)	2.7	Zobel, et al. (6)
Bark	6.8	IPC 3212-3
Bark	10.2	IPC 3212-32

Loblolly pinewood is low in extractives and a level of 3.0% is suggested for use in between-species comparisons. Extractives work done on loblolly pine bark in this project showed an average level of 8.5%. This is also a relatively low level, being less than three of the four hardwoods examined in Progress Report One. In cooperative research done at the Institute, total resin acids in the inner bark amounted to twice the amount found in the outer bark. However, indications are that extractives are not expected to be a serious problem when pulping the bark of this species.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable (or unfavorable) way to the resulting paper product. The principal elements in the bark of loblolly pine having an effect on the pulp are sieve and phellem cells. Two types of phellem cells are involved, thin-walled cork cells and thick-walled stone cells (sclerified cork cells). There are no true fibers in the bark of loblolly pine.

The short, thin-walled sieve cells and the short, thick-walled stone (sclerified phellem) cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. Both types of cells, when subjected to beating, would probably not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve and phellem cells, would

probably be extremely brittle and low in strength. In addition, these cells could contribute to felt plugging and drainage problems.

Under typical kraft pulping (48-52% yield), the cog-shaped stone (phellem) cells usually separate and, as separate entities, should not cause serious problems. However, it appears that in high-yield pulping, many of these stone cells would remain in clumps and could cause so-called "fisheyes" in certain grades of paper much like clumps of sclereids do in hardwood pulps and certain softwoods (hemlock, fir, and spruce). In addition, in the samples of bark pulped at the Institute, many of the peridermal cells from the outer bark retained a dark brown color, indicating the probability that they might present a speck and spot problem in some paper grades.

As a check on pulp yield and the nature of the material produced from loblolly pine, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the results of this investigation. Micropulping of loblolly pine bark resulted in a yield of 20 to 28% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the sieve cells. The on 150-mesh fraction had a high percentage of parenchyma, peridermal and phellem cells. The on 200-mesh and through 200-mesh fractions contained mainly thick-walled cogwheel-shaped phellem cells. Figure 3 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 24 grams of solids will result. Of this 24 grams, about 6 grams (6%) of sieve cells and 1 gram (1%) of phellem cells will be produced. Approximately 1 gram (1%) of other material (parenchyma and peridermal cells) would also result. No truly fibrous material

TABLE III

LOBLOLLY PINE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-3	Sample No. 3212-32	Remarks[a]
Yield, % solids	27.6	19.7	
Fraction			
on 60 mesh, %	23.0	29.4	The bark fraction contained principally sieve cells (90-95%), with small percentages of parenchyma and thin-walled peridermal cells (<5%) and thick-walled cogwheel-shaped phellem cells (<5%). The average length of the sieve cells was 2.25 mm
on 100 mesh, %	7.3	10.7	The fraction contained approximately equal percentages of sieve cells (30-40%), parenchyma and thin-walled peridermal cells (30-40%) and thick-walled cogwheel-shaped phellem cells (30-40%)
on 150 mesh, %	7.0	10.1	The fraction contained large percentages of parenchyma and thin-walled peridermal cells (40-50%), thick-walled cogwheel-shaped phellem cells (40-50%) and a smaller percentage of sieve cells (10-20%)
on 200 mesh, %	3.8	4.9	The bark fraction contained large percentages of thick-walled cogwheel-shaped phellem cells (60-70%), parenchyma and thin-walled peridermal cells (30-40%) with a small percentage of sieve cells (<5%)
through 200 mesh, %	58.9	57.9	The fraction contained principally cogwheel-shaped phellem cells (80-90%) with a small percentage of parenchyma and thin-walled peridermal cells (10-20%) and a trace (<1%) of sieve cells

[a]Percentages given are on a dry weight basis.

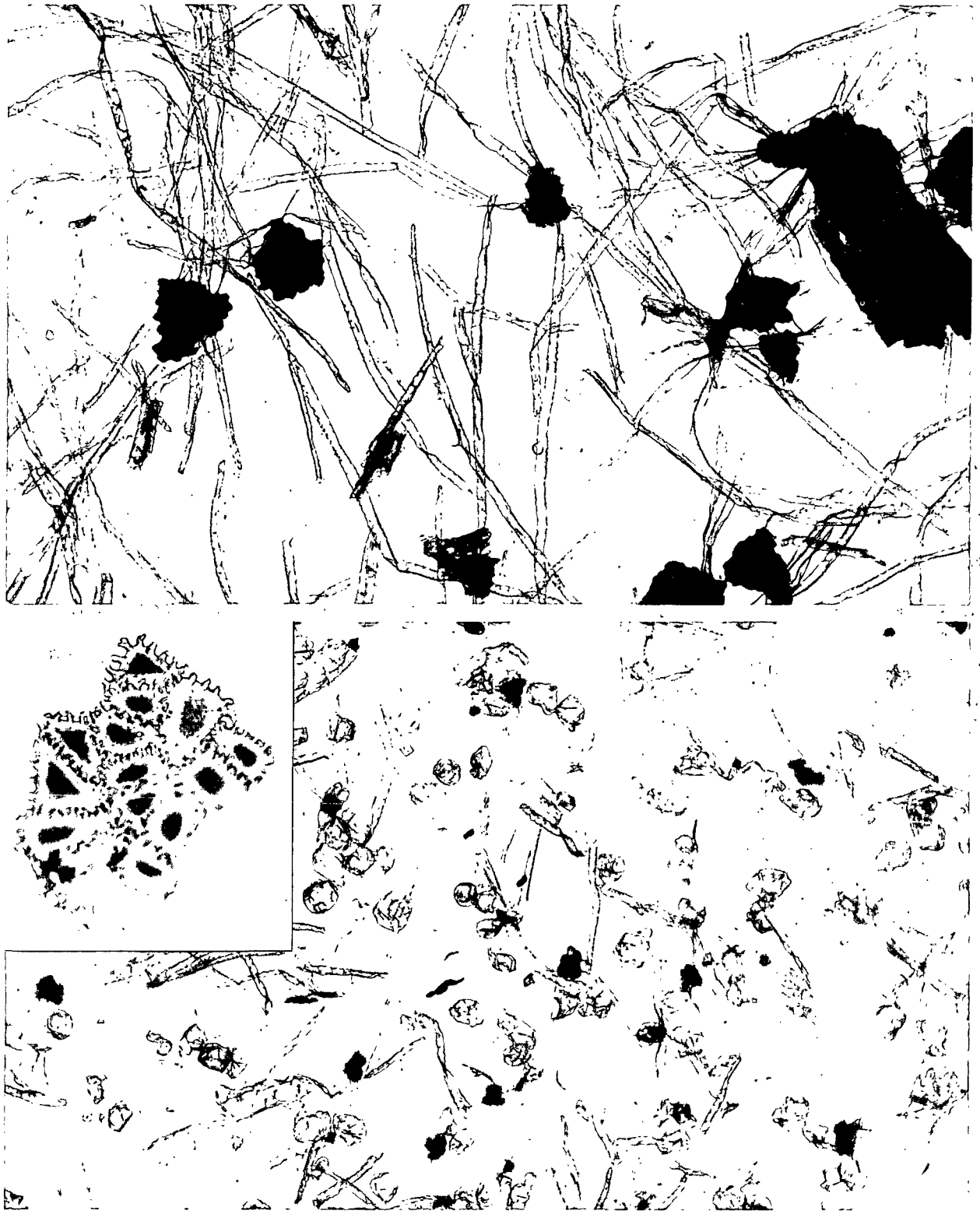

Figure 3. The 60-Mesh Screen (Top) Contained an Estimated 90-95% Sieve Cells and a Minor Number of Clumps of Phellem Cells. The 150-Mesh Screen (Bottom) Contained Equal Amounts of Parenchyma and Thin-Walled Peridermal Cells (40-50%) and Thick-Walled Phellem Cells (40-50%). Insert Shows a Clump of Thick-Walled Cog-Shaped Phellem Cells. Magnification — 35X (185X for Insert)

that will contribute in a favorable way to paper properties will result from the pulping of loblolly pine bark. This assumes that only material on the 60- and 100-mesh screens would end up and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structure associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for loblolly pine samples collected July 29, September 30, and October 7. The July sample was meant to represent growing season adhesion while the September and October samples were collected for dormant season adhesion. Unfortunately, the cambium zones of the later samples were still active, so, at this point, we do not have a value for dormant season adhesion. Another sample of loblolly pine is being obtained and the dormant season adhesion value should be available for a later summary. It is unlikely that the cambium zone of loblolly pine would be active so late every year. Unusual warm, wet weather could have contributed to longer cambium activity.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured.

After testing, the samples were examined to determine the location of the zone of failure. Figure 4 illustrates the zone during the growing season. During the growing season, adhesion values averaged 5.8 kg/cm^2 and the zone of failure was located in the immature newly formed fibers (xylary initials) near the cambium zone and in adjacent nonlignified cells in the cambium zone. It is likely that dormant season values would be close to those of slash pine (9.1 kg/cm^2).

As a result of measurement data taken on the species included in Appendix Table XXVII and the measurement data reported in Progress Report One, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

A number of separation methods have been tried with southern pine. Blackford (20) reported that compression debarking and screening of southern pine slabwood chips resulted in a chip loss of 3.9% and a remaining bark content of 1.1%. This was from an original mixture of chips with 17.4% bark. Arola (21), Erickson (22), and Arola and Erickson (23) obtained similar results with compression debarking. Arola reported 92% bark removal from an original chip/bark

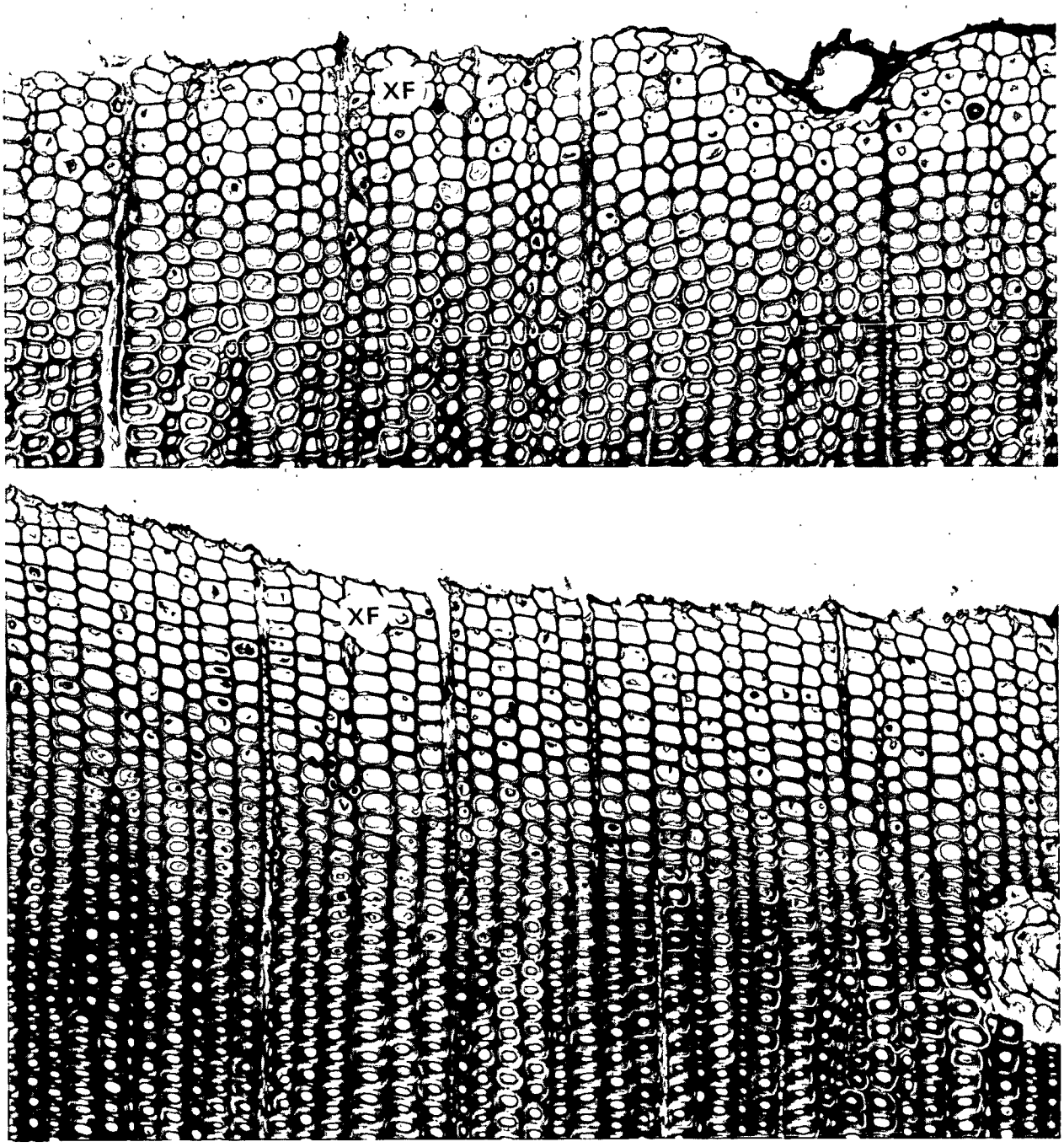

Figure 4. Illustrated Is the Loblolly Pine Failure Zone on July 29 (Top) and October 7 (bottom). Failure for Both Samples Occurred in the Immature Newly-Formed Xylem Fibers (XF) Near the Cambium Zone. There is a Gradation from the Newly Formed Xylem Fibers to the Fully Mature Xylem Tracheids. Magnification — 125X

mixture containing 21.5% bark and a 90.3% wood recovery. Erickson obtained a 96.9% wood recovery with 4.9% residual bark (original bark input 10.3%).

Several approaches that were tried with hardwoods in Project 2929 to reduce adhesion might have some promise with softwoods. They included chemical, thermal, and biological methods. These methods have not been tried with loblolly pine but are worthy of further consideration and are discussed in greater detail in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of loblolly pine.

Relatively small differences were obtained in bark strength and toughness between inner and outer bark while the differences between bark and wood were quite large. In addition, these values were less than those obtained for many of the hardwoods. This is probably due to the lack of fiber in loblolly pine bark. Appendix Table XXVIII summarizes the bark strength values for loblolly pine and includes a number of other species for comparison purposes.

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF LOBLOLLY PINE[a]

Material	Strength	Toughness
Wood	--	0.36
Inner bark	3.7	0.07
Outer bark	3.2	0.04

[a]Determinations made on two different trees.

Summarized in Table V are the results of the hammermilling tests run on loblolly pinewood and bark. Hammermilling, followed by screening, can be expected to result in only a moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 6% loss in wood and a 34% reduction in bark. Figure 5 illustrates the effect of hammermilling on wood and bark of loblolly pine. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions remaining high in bark could be treated by water flotation or some other method. It is also possible improvements could be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 5 (24,25).

TABLE V

SUMMARY OF HAMMERMILLING TEST ON LOBLOLLY PINE

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-3	Bark	20	26	17	8	10	19	Difficult to sort outer from inner bark, but inner bark comprises a very small part of the total bark sample
	Wood	58	30	7	2	2	2	
3212-32	Bark	17	34	16	8	8	16	Same as above
	Wood	73	18	4	2	2	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

WATER-FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

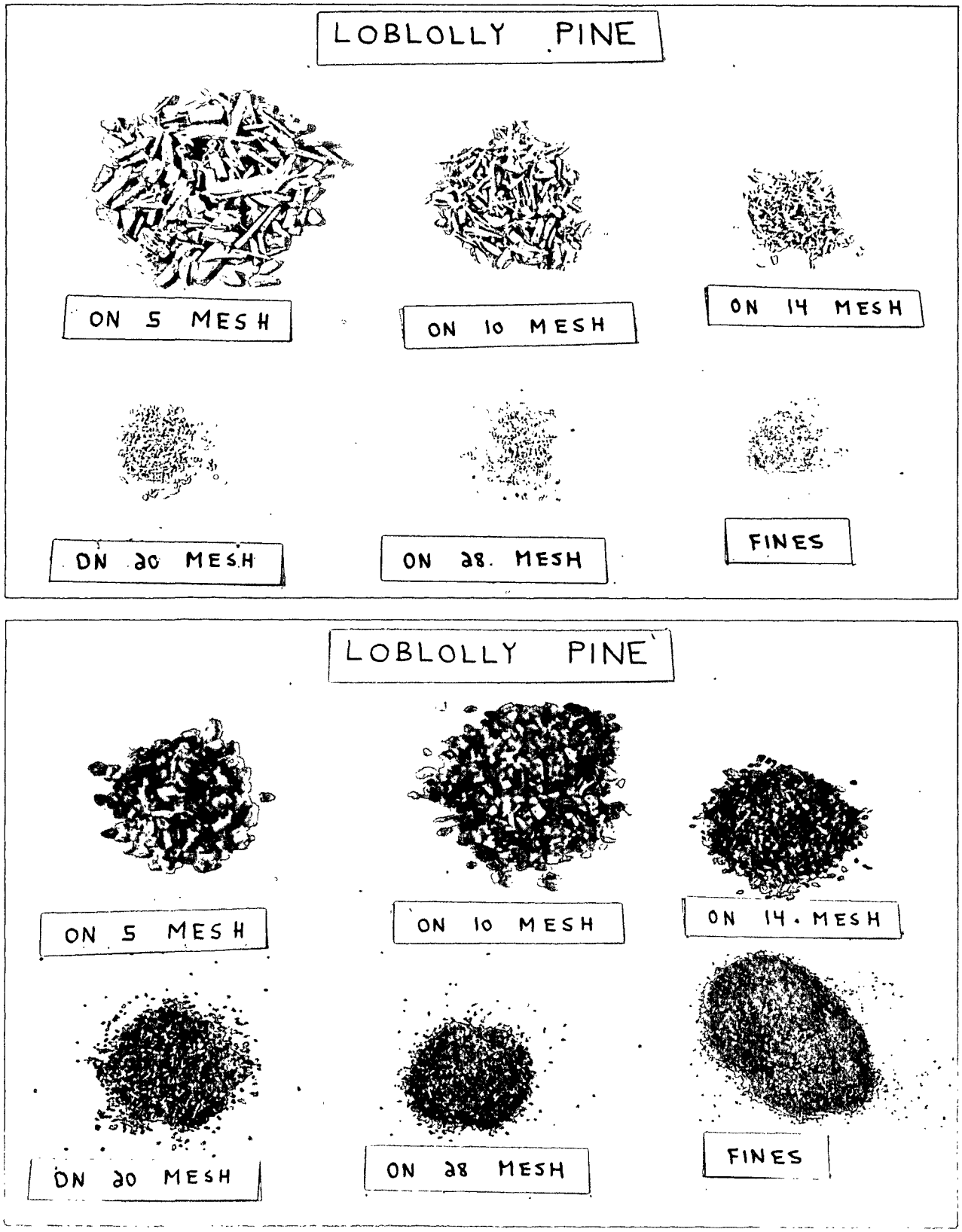

Figure 5. Illustrated Is the Effect of Hammermilling on Loblolly Pine Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two loblolly pine trees (IPC 3212-31 and IPC 3212-32) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark for loblolly pine 3212-31 tended to have approximately the same density as the outer bark, while the inner bark for 3212-32 was slightly higher in density than the outer bark. Differences, however, were minor and it appeared that in a majority of cases the inner and outer bark would behave similarly to total bark under flotation conditions.

Figure 6 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

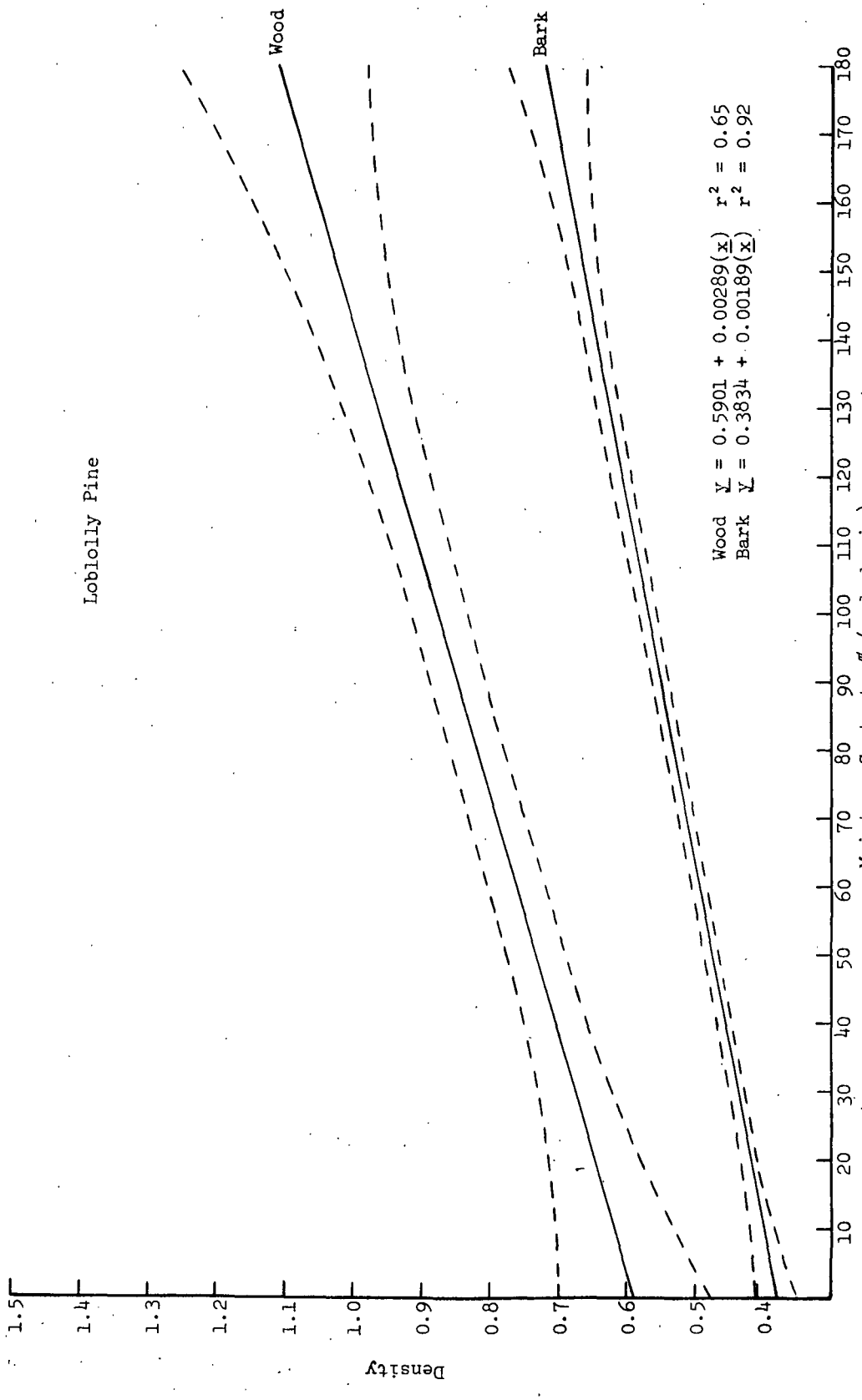

Figure 6. Illustrated Is the Relationship Between Basic Density and Moisture Content for Loblolly Pine. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water-flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that at moisture contents of 145% or greater most wood chips could be expected to sink (density greater than 1). Loblolly pine bark, on the other hand, could be expected to float at moisture contents of 145% or above (density less than 1). However, results with conventional chips probably would not be as clear cut as the density regression lines suggest. The reasons are several. With conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity to the point that a certain part of the total sample will not behave as expected. This is the reason for the wood loss and bark contamination information found in the literature when density measurements suggest good segregation should take place.

Robins (26) reported that optimum segregation of loblolly pine bark and wood chips was achieved by using a steaming and compression debarking pre-treatment. Satisfactory segregation was then achieved by using the Cartesian Diver principle for 45 sec under 60 psig. Results of water-flotation work done

under another project at the Institute (Project 2977) further confirmed that wood tended to sink and bark tended to float. Complete submersion of wood required 144 hours, after which time a high percentage of bark was still floating. Accelerated segregation, with wood sinking and bark floating, was achieved in approximately 15 minutes using a pressure system and chips at 45% moisture content. A high percentage (93-99%) of wood was recovered with a minimum amount of bark contamination.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell-time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table VI summarizes the results for loblolly pine. Density determinations and other reported information indicate that segregation would be accomplished much more effectively and in a shorter length of time when samples with a fairly large density gradient

have a high starting moisture content. The validity of this statement was checked with sugar maple. Previously, when dwell-time tests were run on sugar maple 3212-28 at 20% moisture content (ovendry basis), very little wood sank and then only after an extended period of time. No bark sank at all. After equilibrating samples for ten days with a predetermined amount of water, the wood chips were at 76% moisture content and the bark chips had 71% moisture. When the same dwell time experiment was performed with these chips, all the wood sank immediately. The bark sank as follows: after 5 minutes — 38.4% had sunk, after 15 minutes — 38.4% sunk, after 1 hour — 40.3%, after 4 hours — 45.5%. This graphically illustrates the influence of moisture content on dwell time.

TABLE VI

SUMMARY OF DWELL-TIME RESULTS FOR LOBLOLLY PINE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC3212-31 Wood	after 5	0	100
	15	3.2	96.8
	60	15.0	85.0
	240	26.6	73.4
IPC 3212-31 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-32 Wood	after 5	4.2	95.8
	15	7.2	92.8
	60	14.2	85.8
	240	23.0	77.0
IPC 3212-32 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

Loblolly pine, an extremely valuable pulpwood species, is being chipped without debarking in greater numbers than ever before. Based upon observations made on the bark and wood of loblolly pine, there appear to be several approaches for handling the resulting bark problem. Morphological, extractive and micropulping data confirm that loblolly pine bark can be pulped at normal pulp yields without difficulty. The bark has no usable fiber that contributes to paper strength and the principal morphological structure that might cause speck problems are the cog-shaped, thick-walled phellem cells of the outer bark. Only when extremely high levels of bark are pulped at high pulp yields should clumps of the cog-shaped cells cause paper property problems. Under normal pulping procedures most of these cells separate and are removed by the screening and washing of the pulp. There are large amounts of sieve cells in the bark of loblolly pine and there have been reports of felt plugging from fine fractions that had their origin in the bark. Closed papermaking systems can be expected to accentuate such problems and, when increasing chemical costs are considered, there appears to be a need for a reduction in the overall level of bark being pulped.

Wood/bark adhesion values for loblolly pine are low to moderate in both the growing and dormant season and reasonable separation of bark from wood by the action of the chipper appears possible during most of the year. Both the compression debarking procedure (23) and compression debarking followed by the use of the Cartesian Diver technique (26) appear to be possible ways of producing chips with a minimum of contaminating bark and a maximum total wood recovery. These procedures would, however, be fairly expensive and produce wet rejects that are less useful as fuel.

Chip screening has been reported to be a way of quickly upgrading 60 to 80% of the total wood/bark chip mixture. Screening produced a mixture of large chips (1/2 inch and larger) having only 3 to 5% bark and resulted in the concentration of a large percentage of the total bark problem in the small-sized chip fraction. Processing the small-sized chips by hammermilling followed by screening, compression debarking, or flotation procedures using pressurization techniques like the Cartesian Diver approach are suggested as methods of upgrading the smaller-sized chips that are high in bark. Use of dry mechanical procedures (hammermilling and screening) has the advantage of producing a reject material extremely valuable as fuel. For most products, reduction of the bark level to below 3% is not necessary. Some reduction, however, appears desirable in view of chemical costs and possible problems resulting from equipment wear, felt plugging, etc. The process used with loblolly pine should be selected on a mill-by-mill basis and must take into consideration end-product requirements, energy costs, and such factors as: (1) woodlands and woodyard equipment commitments and (2) mill digester, cleaner and recovery furnace capacity.

RELATED LITERATURE

One method of segregating loblolly pine wood/bark chip mixtures that has not been mentioned previously is the vac-sink process (27). This method has not been used recently because it has proven ineffective with loblolly pine thinnings. Other related literature deals with moisture content in southern pine and includes papers by Besley (10), Choong and Fogg (28), and Zobel, et al. (29). A discussion of mineral content as related to specific gravity, growth rate and distance from the pith can be found in a paper by McMillan (30).

BARK AND WOOD PROPERTIES OF SLASH PINE
(Pinus elliottii Engelm.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

One of the most important of the pines in southeastern United States, the slash pine range extends from the Coastal Plain of southern South Carolina through southeastern Georgia, to central Florida and southeastern Louisiana. By plantings, this range has been extended, as in East Texas where it reproduces naturally. A variety of Pinus elliottii Engelm., the Florida slash pine (Pinus elliottii var. densa) grows from central Florida, south along both coasts to the lower Florida Keys.

The natural range of slash pine is characterized by warm humid weather and usually sandy soils underlain with poorly drained hardpans 18-24 inches below the surface. The best growth is obtained on the margins of shallow, poorly drained depressions known as ponds. Pruning itself well, particularly in dense stands, slash pine heights average 70-80 feet, ranging from 50-110 ft and about 2 ft in diameter at 50 years of age.

WOOD AND BARK MORPHOLOGY

Wood

Indistinguishable in gross features and microscopic structure from other southern pines, the xylem of slash pine consists of fiber tracheids aligned in radial rows, uniseriate and fusiform rays and longitudinal and transverse resin canals. The growth rings are very distinct, delineated by a pronounced band of thick-walled latewood tracheids. The transition from earlywood to latewood is abrupt. The cell-wall thickness of the earlywood fibers is approximately 2.0 μm, while the latewood fibers have a cell wall thickness of approximately

8.0 μm. Slash pine fibers average 4.5-5.0 mm in length and have an average diameter of 40-45 μm. The uniseriate rays are numerous and 1-8+ cells in height. The fusiform rays with transverse resin canals are 12+ cells in height. Marginal and interspersed dentate ray tracheids are present in both types of rays. The longitudinal resin canals average 90-150 μm in diameter while the transverse resin canals are approximately half this size. Thin-walled epithelial cells line the resin canals. Ducts in the heartwood are frequently occluded with tylosoids.

Bark

Comprising approximately 16% of the log volume, the bark of the mature slash pine is about 3/4 to 1-1/2 inches thick. Deeply furrowed, the large, flat plates of rhytidome expose reddish-brown colored phloem tissues and pinkish-colored layers of periderm. The rather narrow inner bark, usually about 1/16-inch wide, is creamy yellow, turning brown after exposure. The outer bark can account for 85-95% of the total bark thickness by weight. This was also the case with trees tested in this project. Figure 7 illustrates a cross section of slash pine wood and bark. Appendix Table XXVI provides information on trees used in this study.

Anatomical Structure of Young Bark

Similar in structure to other southern pines, the young bark of the slash pine is composed of an epidermis, a suggested hypodermis, the periderm, cortex and secondary phloem of parenchyma, sieve cells, and narrow phloem rays. Chang (1) reports two minor variations in young slash pine. Thick-walled cells develop very early in the periderm and sclereids, "lignified" cortex cells retaining their original size and shape, occur in the cortical region.

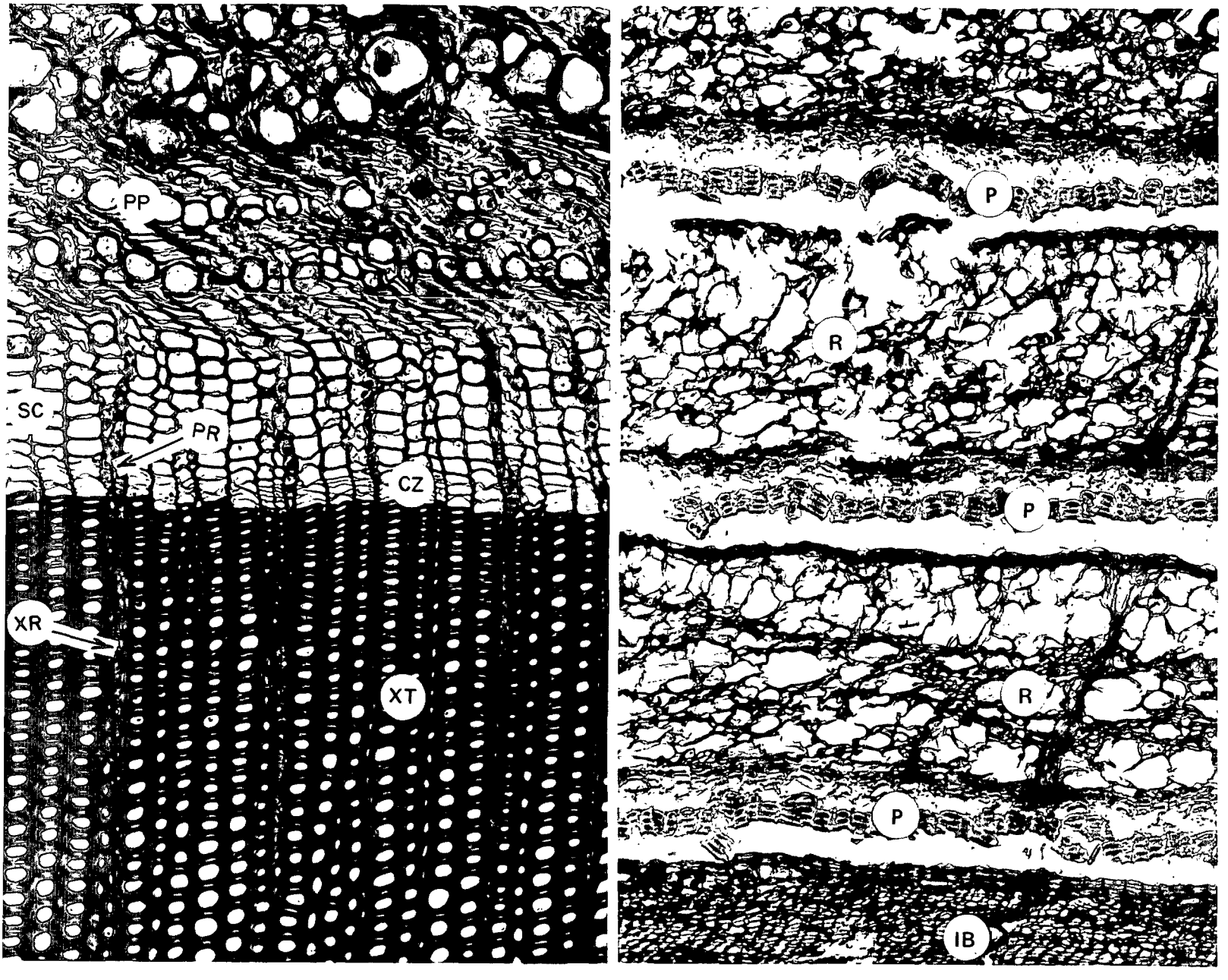

Figure 7. Cross Section of Slash Pine Showing the Wood and Inner Bark (Left) and the Layered Appearance of the Outer Bark (Right). Illustrated Are Sieve Cells (SC), Phloem Parenchyma (PP), Phloem Rays (PR), Cambium Zone (CZ), Xylem Rays (XR), Summerwood Xylem Tracheids (XT), and Inner Bark (IB). The Outer Bark (Rhytidome) of Slash Pine (R) Consists of Alternating Bands of Periderm (P) and Isolated Secondary Phloem. Magnification — 120X Left, 50X Right

Anatomical Structure of Mature Bark

The narrow rhytidome layers are composed of deformed sieve cells and greatly expanded parenchyma and phloem ray cells from the secondary phloem isolated by rather broad periderm layers. Well-developed, the periderm consists of 3-5 layers of phelloderm, a layer of phellogen, and alternating thin and thick-walled phellem cells. Probably "lignified" phelloderm cells, these bands of thick-walled cells (stone cells) show distinct lamellate layers of secondary wall thickenings with simple pits (1).

The inner bark (secondary phloem) of slash pine is composed of radially aligned sieve cells interrupted by tangential lines of sporadically arranged parenchyma cells. According to Chang (1) sieve cells are usually about 25 μm in radial diameter and 40 μm in tangential diameter in cross section and vary in length from 2.4 to 4.6 mm with an average length of 3.48 mm. Oval to circular-shaped sieve areas aligned in single vertical rows are predominantly on the radial walls. In sieve cells close to the cambial area, styloid crystals are present. The phloem parenchyma cells in the proximity of the cambium zone are similar in size and shape to the sieve cells in the same area. After a few seasons' growth, many parenchyma cells expand, squeezing the adjacent sieve cells out of shape and position, and become oval to circular in cross section with diameters often up to 100 μm. The length of a parenchyma strand is usually about the same length as the adjacent sieve cells.

Radially bordering these two types of cells are uniseriate and fusiform phloem rays. The uniseriate rays are usually approximately 10 cells and 300 μm in height. Horizontal resin canals are present in the fusiform rays. These canals are bordered with 3-4 thin-walled epithelial cells.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table VII summarizes the information available on wood and bark of slash pine and, whenever possible, information on bark has been separated into inner and outer bark. Specific gravity is most often expressed in terms of ovendry weight over green volume. It should be noted that several of the values in Table VII are ovendry weights divided by ovendry volumes.

van Buijtenen (31) found that the factors having the greatest influence on the wood specific gravity of slash pine were first summerwood wall thickness, followed by the percentage of springwood and the diameter of summerwood fibers. Specific gravity of the bark of slash pine is usually low to intermediate compared to the wood but this can vary considerably. Differences in specific gravity are probably attributable to the degree of expansion of old phloem cells and to varying proportions of phellem stone cells (3), which is also true for loblolly pine. According to Phillips and Schroeder (4), slash pine bark from plantation-grown trees has a high specific gravity at ground level and then exhibits a

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

downward trend in specific gravity going up the tree. This is somewhat different from loblolly pine which shows increasing specific gravity during the first 25% of merchantable height.

TABLE VII

SLASH PINE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
				0.341	0.302-0.354	Phillips & Schroeder (Ga.) (4)
				0.307	0.268-0.327	Phillips & Schroeder (S.C.) (4)
0.56 (Coastal)						Zobel, et al. (6)
0.56 (Piedmont						Zobel, et al. (6)
0.53 (dbh-5.0-8.9)						Wahlgren & Schumann (9)
0.54 (dbh-9.0-14.9)						Wahlgren & Schumann (9)
0.53						Wahlgren & Schumann (9)
				0.41		Fournier & Goulet (5)
			0.36			Fournier & Goulet (5)
0.59 (dbh disks)						Einspahr, et al. (32)
0.54 (whole tree)						Einspahr, et al. (32)
0.43-0.54						Besley (10)
0.56						Isenberg (11)
0.53		0.32	0.37	0.36		IPC 3212-36
0.55		0.36	0.35	0.35		IPC 3212-37
				0.47[a]		Martin (15)
0.66[a]						Isenberg (11)

[a]Ovendry weight/ovendry volume.

The specific gravity of the total (inner + outer) bark of slash pine is usually lower than that of the wood, although, as mentioned above, this may vary considerably, depending upon the morphology of the particular bark sample. Our limited data show the inner bark to be approximately equal or slightly lower in specific gravity than the outer bark. Overall values suggested for use in species comparisons are 0.54 for wood and 0.34, 0.36 and 0.35 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on alcohol-benzene extractives of wood but much less is known about extractives levels in bark. Table VIII summarizes existing data and includes two slash pine (3212-36 and 3212-37) sampled as part of this project.

Slash pine wood is low in extractives and a level of about 3.3% is suggested for use in between-species comparisons. Extractives work done on slash pine bark suggests a level of 8.4% as appropriate. Both wood and bark

extractives levels of slash pine appear approximately the same as that of loblolly pine. As mentioned in the loblolly pine extractives section, the levels in the bark of both species are relatively low, being less than three of the four hardwoods examined in Progress Report One.

TABLE VIII

SLASH PINE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	2.6	Rydholm (33)
Wood (increment cores)	7.4	Einspahr, et al. (32)
Wood (whole tree)	4.1	Einspahr, et al. (32)
Wood	2.6-6.4	Isenberg (11)
Wood (green)	3.0	Max (34)
Wood (seasoned wood)	2.1	
Wood (juvenile)	5.0	Zobel, et al. (6)
Wood (mature)	1.8	
Bark	14.0	Harkin & Rowe (14)
Bark	5.8	IPC 3212-36
Bark	5.3	IPC 3212-37

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

Since the barks of slash pine and loblolly pine are very similar, most of the comments made about loblolly pine would also apply to slash pine. Again, the principal elements having an effect on the pulp are sieve and phellem cells.

According to Chang (1), 54.2% of the inner bark of slash pine is composed of sieve cells. Two types of phellem cells are involved, thin-walled cork cells and thick-walled stone cells (sclerified cork cells). There are no true fibers in the bark of slash pine.

The thin-walled sieve cells and the thick-walled stone (phellem) cells could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. Both types of cells, when subjected to beating, would probably not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve and phellem cells, would probably be extremely brittle and low in strength. In addition, sieve tube and phellem cell fines could contribute to felt plugging and drainage problems.

Under typical kraft pulping (48-52% yield), the cog-shaped stone (phellem) cells usually separate and, as separate entities, should not cause serious problems. However, it appears that in high yield pulping, many of these stone cells would remain in clumps and could cause so-called "fisheyes" in certain grades of paper much like clumps of sclereids do in hardwood pulps and certain softwoods (hemlock, fir, spruce). In addition, in the samples of bark pulped at the Institute, many of the peridermal cells from the outer bark retained a dark brown color, indicating the probability that they might present a speck and spot problem in some paper grades. This was also true of loblolly pine.

As a check on pulp yield and the nature of the material produced from slash pine, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micro-pulping Procedure. Table IX summarizes the results of this investigation. Micro-pulping of slash pine bark resulted in a yield of 20 to 28% solids. When screened,

TABLE IX

SLASH PINE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-36	Sample No. 3212-37	Remarks[a]
Yield, % solids	19.7	27.6	
Fraction			
on 60 mesh, %	27.2	18.8	The fraction contained a large percentage of sieve tubes (70-80%) with smaller percentages of cogwheel-shaped phellem cells (20-30%) and parenchyma and thin-walled peridermal cells (<5%). The average length of the sieve cells is 2.2 mm
on 100 mesh, %	10.2	7.6	The fraction contained large percentages of sieve cells (50-60%), cogwheel-shaped phellem cells (40-50%) and a small percentage of parenchyma and thin-walled peridermal cells
on 150 mesh, %	13.2	10.4	The fraction contained a large percentage of thick-walled cogwheel-shaped phellem cells (70-80%) and smaller percentages of perenchyma and thin-walled peridermal cells (10-20%) and sieve cells (5-10%)
on 200 mesh, %	11.4	9.2	The fraction contained a large percentage of thick-walled cogwheel-shaped phellem cells (70-80%), a smaller percentage of parenchyma and thin-walled peridermal cells (10-20%) and a trace of sieve cells (1-2%)
through 200 mesh, %	38.0	54.0	The fraction contained principally cogwheel-shaped phellem cells (90-95%), a small percentage of parenchyma and thin-walled peridermal cells (5-10%) and a trace of sieve cells (<1%)

[a]Percentages given are on a dry weight basis.

the coarse screens (60 and 100 mesh) retained most of the sieve cells. The on 150-mesh fraction had a high percentage of phellem cells. The on 200-mesh and through 200-mesh fractions also contained mainly the thick-walled cogwheel-shaped phellem cells. Figure 8 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that for every 100 grams of bark that is pulped, about 24 grams of solids will result. Of these 24 grams, about 6 grams (6%) of sieve cells and 2 grams (2%) of phellem cells will be produced. This is only slightly different than the amounts of material produced from loblolly pine bark. Again, this assumes that only material on the 60- and 100-mesh screens would end up and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structure associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in slash pine was studied extensively in Project 2929 (Progress Report Three) and the work was not repeated but a summary of the results of earlier investigations follows.

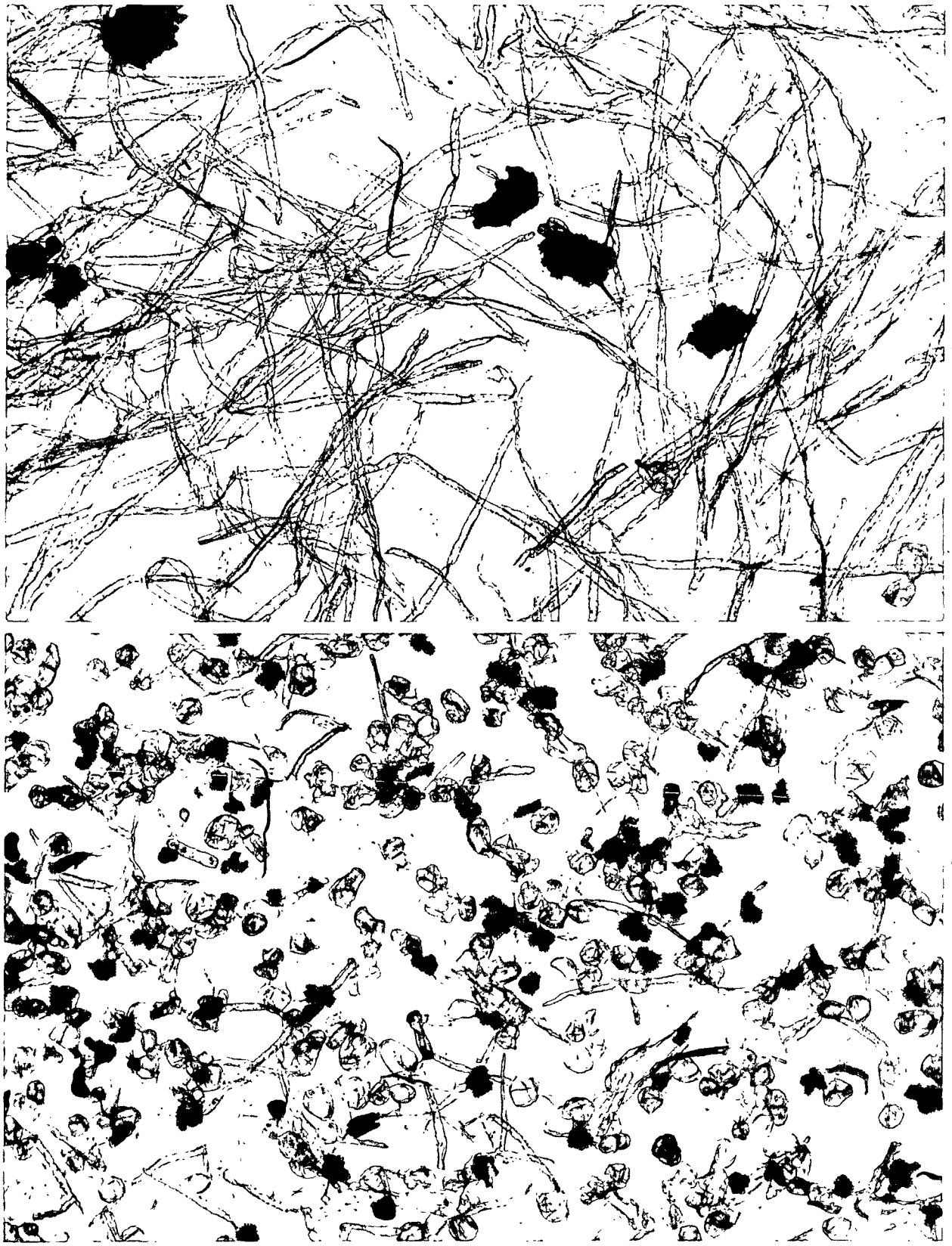

Figure 8. The 60-Mesh Screen (Top) Contained Primarily Sieve Tubes (70-80%) with Smaller Percentages of Stone (Phellem) Cells (20-30%). The 150-Mesh Screen (Bottom) Contained a Large Percentage by Weight of Phellem Cells (70-80%) and Smaller Amounts of Parenchyma, Peridermal and Sieve Cells. Magnification — 35X

Dormant season samples collected in February and March revealed a cambium zone 5 to 6 cells in width and, when adhesion tests were made, failure quite consistently occurred in the inner bark sieve and parenchyma cells near the cambium. The one August dormant sample tested also had a cambium zone 5-6 cells in width and failure in this sample occurred between the cambium zone and partially lignified tracheids. During the growing season, wood/bark adhesion decreased and failure occurred either in the cambium zone, in the inner bark very near the cambium zone, or in the most recently formed fibers (xylem initials). Figure 9 illustrates the changes in location of the zone of failure and Appendix Table XXVII gives the magnitude of wood/bark adhesion values involved. Included for comparison purposes are the results of wood/bark adhesion tests run on several other tree species. Adhesion values for slash pine averaged 3.5 kg/cm^2 during the peeling season and 9.1 kg/cm^2 during the dormant season.

As a result of measurement data taken on the species included in Appendix Table XXVII and the measurement data reported in Progress Report One, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

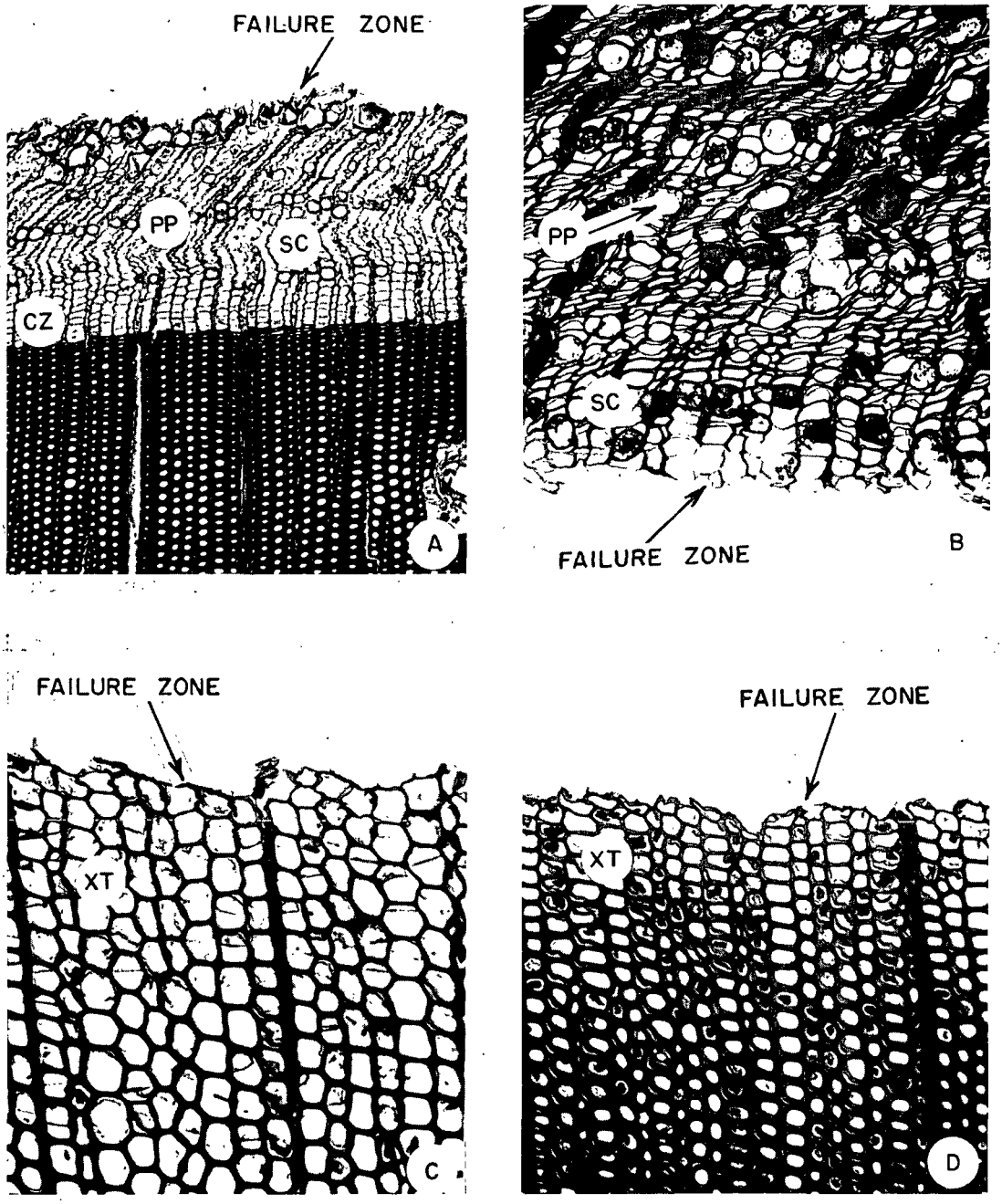

Figure 9. Seasonal Changes in the Zone of Failure in Slash Pine Are Illustrated Above; A — February 15 Collection, Failure in Inner Bark in Sieve (SC) and Parenchyma Cells (PP) Well Outside the Cambium Zone (CZ); B — March 15 Collection, Failure Occurred in Inner Bark Sieve (SC) and Parenchyma Cells (PP) Near the Cambium Zone; C — May 10 Collection, Failure Occurred Just Inside the Cambium Zone Between Immature and Maturing Xylem Tracheids (XT); D — August 2 Collection, Cambium Still Active and Failure Occurred Between Xylem Initials and Immature Tracheids (XT) that Show Some Lignification

Some of the methods of separation mentioned under loblolly pine would also apply to slash pine. Blackford (20) reported that compression debarking and screening of southern pine slabwood chips resulted in a chip loss of 3.9% and a remaining bark content of 1.1%. This was from an original mixture of chips with 17.4% bark. Arola (21) obtained similar results with compression debarking. He reported 92% bark removal from an original chip/bark mixture containing 21.5% bark and a 90.3% wood recovery.

As discussed previously, several of the approaches that were tried with hardwoods in Project 2929 to reduce adhesion might have some promise with softwoods. They included chemical, thermal and biological methods. These methods have not been tried with slash pine but are worthy of further consideration and are discussed in greater detail in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of slash pine. Relatively small differences were obtained in bark strength and toughness between inner and outer bark, while the differences between wood and bark were quite large. (This was also the case for loblolly pine.) In addition, these values were less than those obtained for many of the hardwoods. This is probably due to the lack of fibers in slash pine bark. Appendix Table XXVIII summarizes the bark strength values for slash pine and includes a number of other species for comparison purposes.

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF SLASH PINE[a]

Material	Strength	Toughness
Wood	--	0.35
Inner bark	6.4	0.06
Outer bark	5.2	0.08

[a]Determinations made on two different trees.

Summarized in Table XI are the results of the hammermilling tests run on slash pine wood and bark. Hammermilling, followed by screening, can be expected to result in only a moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 5% loss in wood and a 36% reduction in bark. Figure 10 illustrates the effect of hammermilling

on wood and bark of slash pine. It is possible that a quick separation could be made by screening, hammermilling the fractions high in bark (small-sized chips), and rescreening and treating the fractions remaining high in bark by water flotation or some other method. As with loblolly pine, it is possible improvements could also be made in screening by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 10 (24,25).

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON SLASH PINE

		Fraction Retained on Standard Screen[a], %						
Tree No.	Type Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-36	Bark	19	26	17	9	10	18	Difficult to sort outer from inner bark but inner bark comprises a very small part of the total bark sample
	Wood	60	30	6	2	1	2	
3212-37	Bark	19	27	17	9	11	16	Same as above
	Wood	49	40	6	2	1	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

WATER-FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water-flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip-washing procedures are employed. Earlier investigations into water-flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood

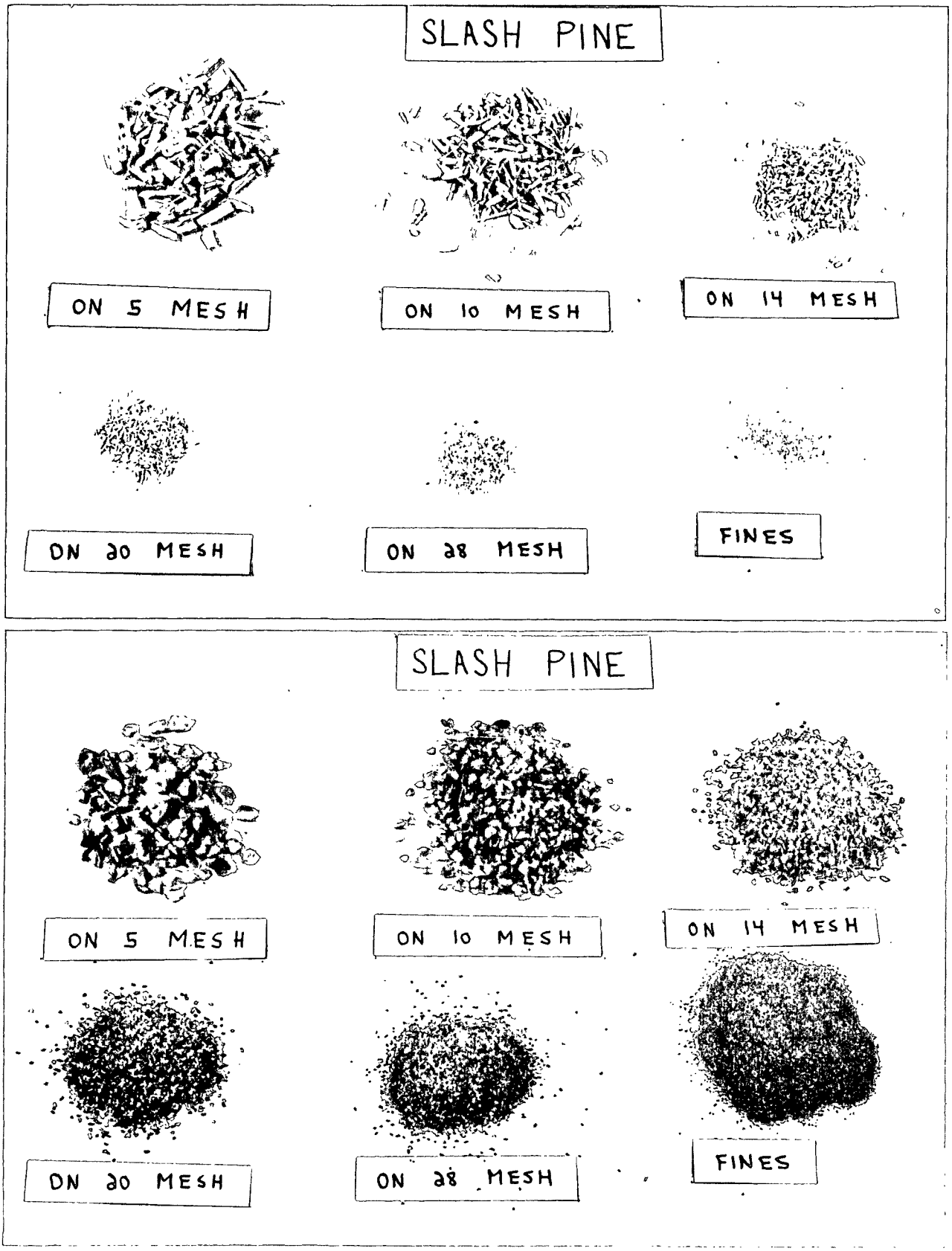

Figure 10. Illustrated is the Effect of Hammermilling on Slash Pine Wood (Top) and Bark (Bottom)

chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water-flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell-time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two slash pine trees (IPC 3212-36 and IPC 3212-37) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark tended to have a slightly higher density than the outer bark for both trees tested.

Figure 11 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

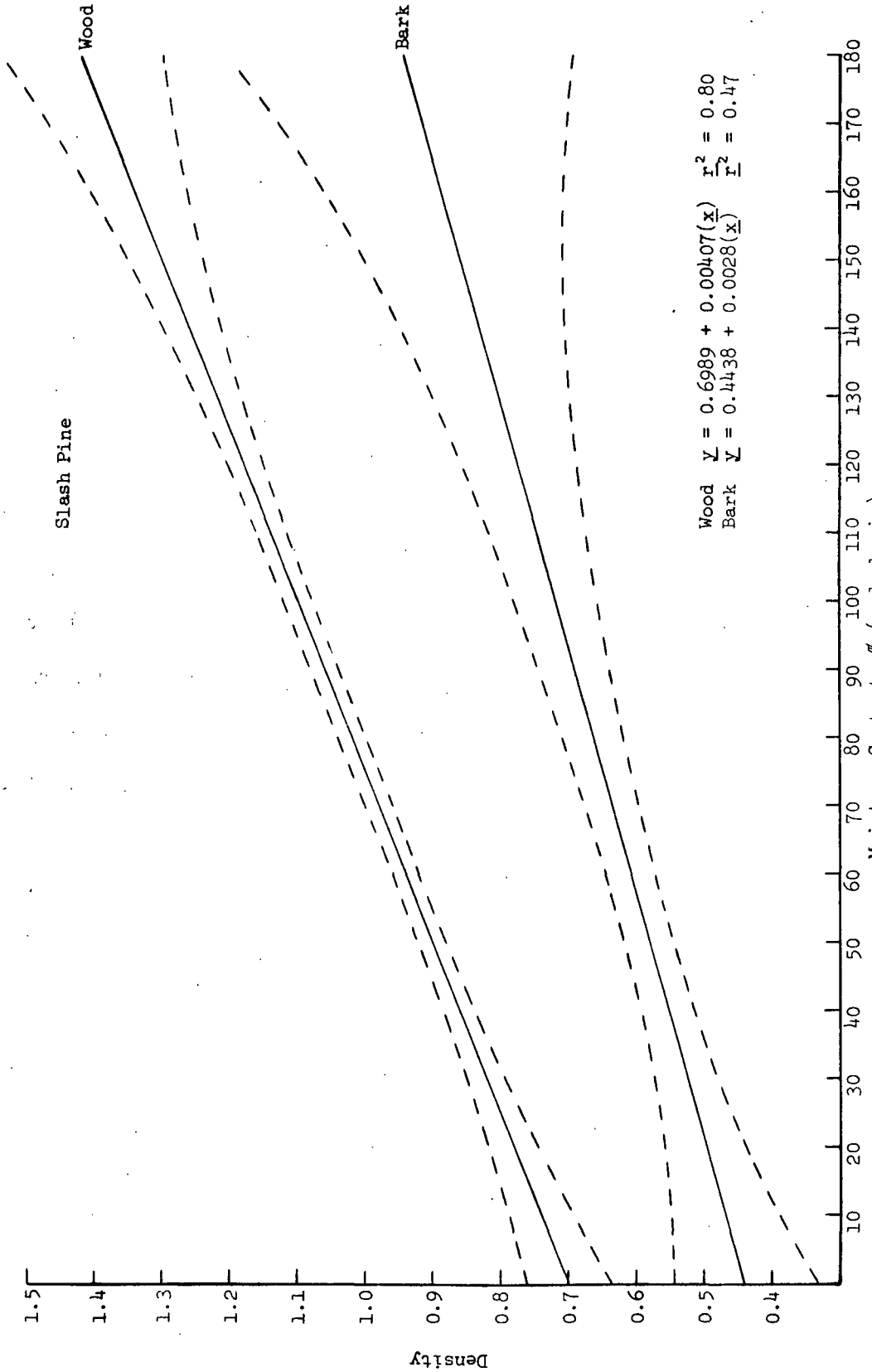

Figure 11. Illustrated Is the Relationship Between Basic Density and Moisture Content for Slash Pine. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water-flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that at moisture contents of 80% or greater most wood chips could be expected to sink (density greater than 1). Slash pine bark, on the other hand, could be expected to float at moisture contents of 80% or above (density less than 1). However, results with conventional chips would probably not be as clear cut as the density regression lines suggest. The reasons are several. With conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity to the point that a certain part of the total sample will not behave as expected. This is the reason for the wood loss and bark contamination information found in the literature when density measurements suggest good segregation should take place.

The results for slash pine look better than for loblolly pine, particularly the lower moisture content needed to effect segregation of wood and bark chips. It appears that the treatments that worked well with loblolly pine should

work equally well or better with slash pine. These included a steaming and compression debarking pretreatment followed by use of the Cartesian Diver principle (26). Water-flotation work with loblolly pine at The Institute of Paper Chemistry required 144 hours for complete submersion of the wood (much of the bark still floating). It would appear that the time required for slash pine wood to sink would be reduced considerably.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell-time tests. Prior to testing, the samples were equilibrated in 50% RH and had moisture contents of approximately 20% (ovendry basis). Table XII summarizes the results for slash pine. The dwell-time investigations confirmed that slash pine wood will sink more readily in water than loblolly pine. After 4 hours, 49 and 67% of the wood chips from the two slash pine samples had sunk vs. 23% and 27% for the loblolly pine samples.

TABLE XII

SUMMARY OF DWELL-TIME RESULTS FOR SLASH PINE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-36 Wood	after 5	13.1	86.9
	15	30.3	69.7
	60	43.6	56.4
	240	66.7	33.3
IPC 3212-36 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-37 Wood	after 5	1.9	98.1
	15	8.8	91.2
	60	32.0	68.0
	240	49.0	51.0
IPC 3212-37 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

Since the bark and wood of slash and loblolly pine are so similar, most of the comments pertaining to one would also apply to the other. Morphological, extractive and micropulping data confirm that slash pine bark can be pulped at normal pulp yields without difficulty. The bark contains no usable fiber. It does contain thick-walled stone (sclereid phellem) cells and thin-walled sieve cells which could be used as filler material in paper but which would probably not contribute in any useful way to paper properties. In addition, under high-yield pulping, clumps of stone cells would not separate readily and could cause "fisheyes" in certain grades of paper. Phellem cells could also contribute

to felt plugging and drainage problems and peridermal cells might present a speck and spot problem. Closed papermaking systems could be expected to accentuate these problems and make removal of at least part of the bark desirable.

Wood/bark adhesion values for slash pine were low to moderate for both growing and dormant season samples and reasonable separation between bark and wood should be possible by chipper action during much of the year. Compression debarking (21) and compression debarking followed by use of the Cartesian Diver principle (26) appear to be ways of producing relatively bark-free chips. The Cartesian Diver technique (or simple flotation procedures) should work even better for slash pine than it does for loblolly pine as slash pine possesses somewhat better flotation characteristics. The disadvantage of this technique lies in the necessity to dry rejected material if it were to be used as fuel.

Use of dry segregation techniques (hammermilling and screening) has the advantages of being both simpler to do and also allowing the rejected material to be used as fuel without further preparation. Screening results in relatively bark-free large chips (1/2 inch and larger) and concentrates the bark in smaller-sized chip fractions. Only these smaller-sized chips would then need further treatment. Processing the smaller-sized chips by hammermilling, followed by screening, (5% loss in wood and 36% reduction in bark in IPC trials), compression debarking or flotation procedures are suggested as ways of upgrading slash pine wood/bark chip mixtures. A screening technique that would take advantage of the shape differences in wood and bark chips after hammermilling is worthy of further investigation. For most products, reduction of the bark level to below 3% is not necessary. Some reduction appears desirable, however, in view of chemical costs and possible problems

resulting from equipment wear, felt plugging, etc. As with loblolly pine, the process selected should be based upon considerations such as end-product requirements, energy costs, equipment commitments and digester, cleaner and recovery furnace capacity.

RELATED LITERATURE

During the process of reviewing and assembling the information on the bark and wood of slash pine, a number of papers containing related information were reviewed. These papers included references on moisture content in southern pine by Besley (10), Choong and Fogg (28), and Zobel, et al. (29). Also noted was a paper on oleoresin yields of slash pine by Squillace and Gansel (35).

BARK AND WOOD PROPERTIES OF DOUGLAS-FIR
(Pseudotsuga menziesii)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Douglas-fir, one of the world's most familiar and valuable timber trees, grows extensively through western North America. Having an enormous north-south range of over 3000 miles, from central British Columbia to central California, it is found from the Pacific coast to the eastern slope of the Rocky Mountains. Universally, botanists recognize Pseudotsuga menziesii var. glauca as the Rocky Mountain variety of Douglas-fir which occurs on the east slopes of the Cascade Range, Sierra Nevada and in the Rocky Mountains. This variety differs from Pseudotsuga menziesii var. menziesii, the coastal form, in foliage color, cone form, growth rate and environmental conditions. The coastal form grows better, is the second largest tree in the United States, and is commercially more valuable.

More intolerant than most of the coastal species, Douglas-fir grows in a mild and humid region and reaches its best development in western Oregon and Washington on soils with pH values of 5-5.5. Under favorable conditions, tree growth is rapid and in virgin forests heights average 180-250 ft, although heights of 325 ft and diameters of 8-10 ft are not uncommon in the coastal variety. The Rocky Mountain form averages 130 ft in height and 3 ft in diameter. Early growths of the species form extensive, pure, even-aged stands which later may be invaded by species of ponderosa, lodgepole, and western white pines. Even within the normal environment range, Douglas-fir has become so adapted to many different combinations of soil and climate that it cannot be indiscriminately transferred from southern to northern latitudes or low to high elevations.

WOOD AND BARK MORPHOLOGY

Wood

Douglas-fir wood is quite variable in color, ring width and strength. The sapwood varies from whitish to pale yellow or reddish white with a heartwood ranging from yellow to deep red. Earlywood is usually several times wider than latewood with an abrupt transition. Growth rings are conspicuous and frequently wavy. The xylem consists primarily of longitudinal tracheids aligned in radial rows, uniseriate and fusiform rays, and resin canals. Fiber tracheids, averaging 35-45 μm in diameter and 3.9 mm in length, are characterized by fine bands of spiral thickenings. Longitudinal parenchyma are very sparse or absent. Ray tracheids, nondentate and occasionally with spiral thickening, are present in both types of rays which occupy approximately 7.3% of the total wood volume. Uniseriate rays are quite numerous and 1-25 cells in height. Fusiform rays are scattered with one or rarely two transverse resin canals which are 3-5 seriate through the central thickened portion, and up to 16+ cells in height. Thick-walled epithelial cells line the resin canals of Douglas-fir. The larger longitudinal canals average 60-90 μm in diameter, and the transverse canals, which show a tendency toward alignment in tangential rows of 2-20+, usually less than 25 μm.

Bark

Rather smooth and grayish on young trees, on the mature tree Douglas-fir bark appears as thick reddish-brown ridges separated by deep irregular fissures. Quite variable, it is usually 1-2 inches thick in thin-barked trees and 5-6 inches and up to 12-24 inches in very old thick-barked trees. Douglas-fir samples tested at the Institute had very thin bark (3/8 inch or less),

typical of young, small-diameter trees.* Percentage by weight of inner and outer bark ranged from approximately 50% of each on a very thin-barked sample (3212-23) to 70% outer bark on 3212-24. The periderm, thin in young stems, is well developed in old or thick-barked trees and in cross section is variable from fine lines to very broad bands of about 1/2-inch wide composed of 15 or more rows of periderm cells. The light, creamy yellow periderm bands are in great contrast to the deep, brilliant-brown, fibrous isolated secondary phloem tissue of the rhytidome. Lighter in color, the inner bark is about 1/8 to 1/4-inch thick. Cork, which originates from the cork cambium, exists in large quantities in Douglas-fir bark (30-50% of the bark dry weight) and has a great effect on bark properties. Douglas-fir bark ranges between 8 and 15% of the log volume on a cubic foot basis (36). Figure 12 illustrates some of the described elements that comprise the wood and bark of Douglas-fir. Appendix Table XXVI describes the trees used in this study.

Anatomical Structure of Bark

As little information is available on the structure of young bark specifically, the anatomical description is for Douglas-fir bark in general. Variations with tree age are noted when known.

Originating from the vascular cambium, the rather narrow inner bark (secondary phloem) of Douglas-fir is composed of 3 major types of vertical elements; sieve cells, sclereids or bast/phloem fibers, and parenchyma cells. Near the cambial zone, thin-walled sieve cells are regularly arranged, usually 3 in a radial row interspersed with parenchyma cells. Varying with the specimen and tree age, sieve cells average 3-4 mm in length. Sieve areas appear on the

*Two other Douglas-fir samples received also had relatively thin bark, 1/2 inch or less.

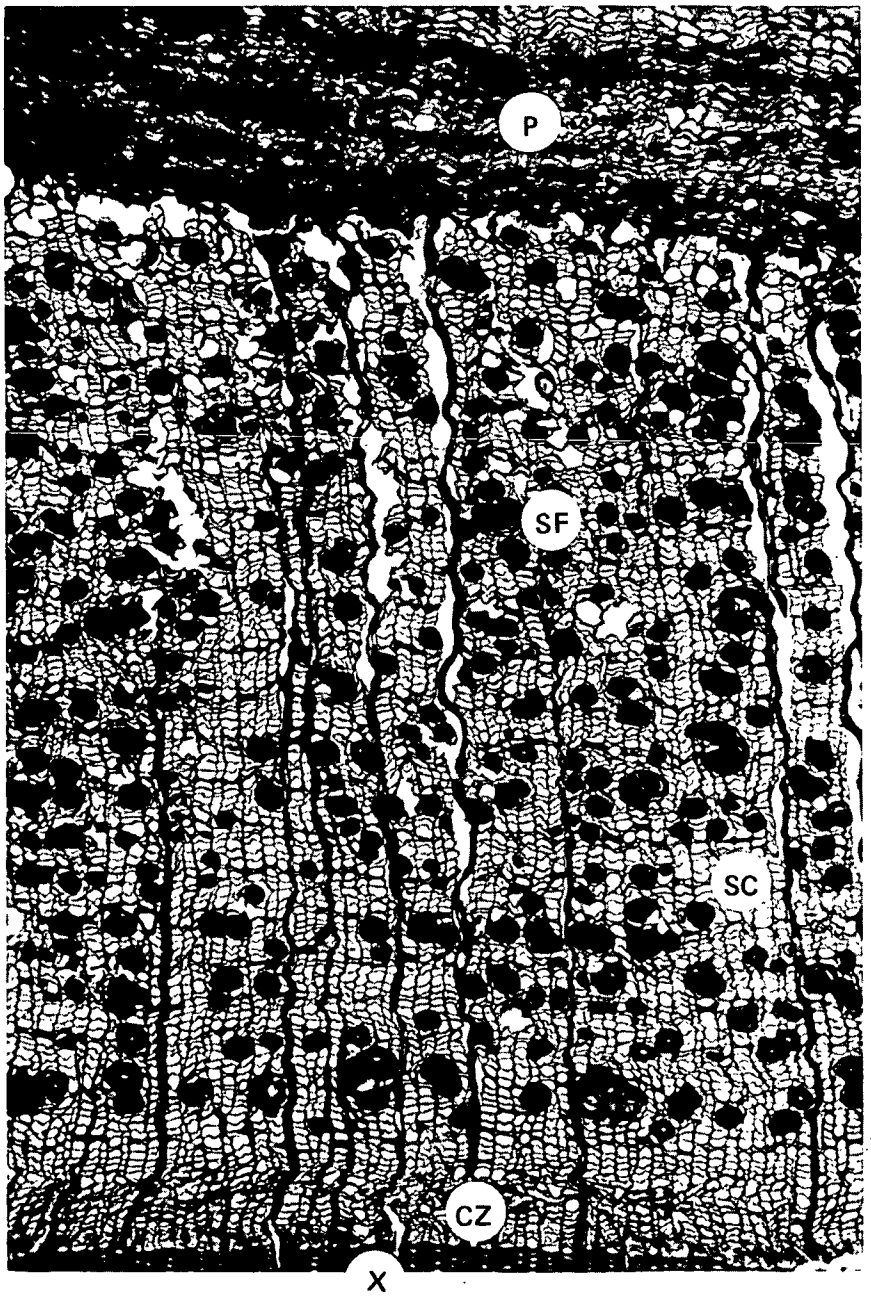

Figure 12. Cross Section of Douglas-fir Bark. Illustrated Is a Small Section of the Xylem (X), the Cambium Zone (CZ), Sieve Cells (SC), Sclereid-like Fibers (SF) and Periderm (P). Shown Is the Inner Bark, Region Between the Cambium Zone (CZ) and the Last Formed Periderm (P), and a Single Periderm Layer. Depending on Tree Age, There Are Normally Many Periderm Bands that Alternate with Areas of Isolated Secondary Phloem. Magnification — 50X

radial walls usually in single vertical rows. As distance increases from the cambium, the sieve cells collapse and become obliterated. Sclereidlike phloem fibers differentiate from cells in the parenchyma strands rather early, some during the third year, and gradually increase in number for years. Comprising most of the bark volume by weight with the exception of the "cork," these fibers appear singly or in groups of 2-6 without definite pattern. Cell walls are very thick with distinct lamellate layers. Although branched and forked forms are not uncommon, most of these sclereids are elongated with pointed ends, with diameters of 50-100 μm and an average length of 1-1.5 mm.

Three types of parenchyma prevail in the secondary phloem. Thin-walled parenchyma cells are somewhat rectangular in cross section and up to 50 μm in diameter close to the cambium, becoming more oval and expanding in the outer bark. Parenchyma strands are the most abundant form and, longitudinally, some have the same length as the sieve cells. Dispersed parenchyma strands are very common in young trees and the cells that do not sclerify, increase in diameter each year crushing the sieve cells. Fusiform parenchyma are much more abundant in the secondary phloem of young trees with only a small percentage in older trees. This form differs from the strand parenchyma in that most of the cells accumulate a clear resinous material and develop cubical crystals after which the cells collapse radially and become crushed. Marginal erect cells, or albuminous cells that do not collect tannins, resins or crystals are conspicuous along the margins of the uniseriate rays close to the cambial zone and may occur in strands.

Rays are of two types, usually uniseriate and fusiform. Uniseriate rays, in young trees only a few cells high, are usually 8-15 cells high or

200-350 μm in height in tangential section. Fusiform rays, absent in young stems, are abundant in older trees and contain the horizontal resin canals (37).

The thick outer bark is formed from alternating layers of isolated secondary phloem tissues and periderm bands. Periderm is usually composed of 2-3 layers of phelloderm, a layer of phellogen and a broad phellem varying in number of cells and layers. Phellem (cork) cells are mainly thin-walled and smaller than parenchyma, but occasionally thick-walled lignified cells are sporadically distributed. With the sieve cells mostly obliterated, expanded parenchyma and sclereidlike phloem fibers predominate in the old inner bark tissues.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Specific gravity of the wood of Douglas-fir has been measured by a number of individuals. There appears to be a slight difference between the specific gravity of the coastal and Rocky Mountain varieties with the coastal invariably being higher. Again, as with many species, there does not appear to be much information available on bark specific gravity. Table XIII summarizes

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE XIII

DOUGLAS-FIR SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	Reference and Remarks
		0.451	0.427			Smith & Kozak (38)
				0.50		Fournier & Goulet (5)
0.45				0.43		Smith (39)
0.45	0.33-0.59 (Coast type)					Wood Handbook (7)
0.41 (intermediate)						Wood Handbook (7)
0.40 (Rocky Mountain)						Wood Handbook (7)
0.40 (Rocky Mountain)						Besley (U.S.) (10)
0.20 ± 10% (earlywood)						Wilson & Ifju (40)
0.62 ± 10% (latewood)						Wilson & Ifju (40)
0.45 (Coastal)						Isenberg (11)
0.40 (Rocky Mountain)						Isenberg (11)
0.44 (sapwood)		0.41	0.43	0.42		IPC 3212-23
0.41 (heartwood)						
0.45 (sapwood)		0.41	0.35	0.39		IPC 3212-24
0.39 (heartwood)						
0.43 (Rocky Mountain)						Brown, et al. (41)
0.45 (Coastal)						Brown, et al. (41)
0.41						Smith (42)
				0.544[a]		Harkin & Rowe (14)
				0.411[a]		Harkin & Rowe (14)
0.51[a] (Coastal)						Isenberg (11)
0.45[a] (Rocky Mountain)						Isenberg (11)
0.44[b]			0.48[b]			Cassens (43)

[a]Ovendry weight/ovendry volume.

[b]Ovendry weight/volume at 13 ± 2% moisture content.

the information available and, whenever possible, information on bark has been separated into inner and outer bark. Specific gravity is most often expressed in terms of ovendry weight over green volume. It should be noted that several of the values in Table XIII are expressed in other ways.

The specific gravity of the bark of Douglas-fir is approximately equal to that of the wood. Our limited data do not show any clear-cut trends in the relationship of inner bark specific gravity to outer bark specific gravity. Overall values suggested for use in species comparisons are 0.43 for wood and 0.42, 0.40 and 0.41 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on extractives levels of Douglas-fir wood but much less is known about the bark. Table XIV summarizes existing data and includes two trees (3212-23 and 3212-24) sampled as part of this project.

Douglas-fir wood is low in extractives and a level of 4.0% is suggested for use in between-species comparisons. Extractives work done on Douglas-fir

bark in this project showed an average level of 16.4%. This is almost twice the levels of loblolly and slash pine and this relatively high level of extractives might cause problems in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other techniques.

TABLE XIV

DOUGLAS-FIR ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.4	Rydholm (33)
Wood (heartwood)	5.1	Wilson & Campbell (44); Campbell, et al. (45)
Wood	4.4	Isenberg (11)
Wood	1.5-5.7	Isenberg (11)
Bark	17.3	IPC 3212-23
Bark	15.4	IPC 3212-24

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of Douglas-fir having an effect on the pulp are sclereidlike fibers, sclereids and sieve cells.

The sclereids in Douglas-fir were short, branched and thick-walled. No record of short, branched, thick-walled, irregular-shaped sclereids was found in the literature for Douglas-fir bark. Chang (46) reports only sclereidlike

fibers for the sclerenchyma present in the species. Both pulp samples of Douglas-fir bark contained short, branched, thick-walled sclereid cells, particularly the "on 100" and "on 150-mesh" fractions. The sclereidlike fibers had a width of between 50 and 75 μm. The majority of these type cells had a very narrow lumen, sometimes even closing, so that the opposite walls touched each other. Hall (47) reports that the crude fiber fraction of Douglas-fir bark, physically separated, averages about 40%. Further refinement reduced bark fiber content to about 22%. He further states that the refined fiber, a product of "alkaline extraction," is meeting with considerable success as an ingredient for improving strength and other properties of resins. However, it is questionable of what value the elongated fiber-type sclerenchyma in Douglas-fir bark would be in most pulp furnishes other than increasing yield, since they would be extremely stiff, would not fibrillate, would have low bonding strength, etc. The sieve cells would also act mainly as filler material. Unscreened yields of 34.6, 45.5, 43.6, 42.7, and 47.0%, respectively, (o.d. wood basis) were obtained by Hatton and Keays (48) for branches, unmerchantable tops, roots, stumps, and boles. They felt immediate consideration should be given to using the unmerchantable top together with the bole. Branchwood pulp could be used with other tree component pulp but, because of the substantial difference in pulp permanganate number, they should not be cooked together.

As a check on pulp yield and the nature of the material produced from Douglas-fir, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XV summarizes the results of this investigation. Micropulping of Douglas-fir bark resulted in a yield of 17 to 18% solids. When screened, the coarse screens (60 and 100 mesh) retained much of the sclereids and sclereidlike fibers. The on 150-mesh fraction had a high percentage of sclereids. The on 200-mesh and through 200-mesh fractions contained mainly

TABLE XV

DOUGLAS-FIR MICROPULPING INVESTIGATIONS

Data	Sample No. 3212-23	Sample No. 3212-24	Remarks[a]
Yield, % solids	18.1	17.1	
Fraction			
on 60 mesh, %	49.5	42.8	The fraction contained thick-walled elongated sclereidlike fibers (average length 1.0-1.5 mm) 50-60%, sieve cells (30-40%), and short branched thick-walled sclereids (10-20%). The average length of the sieve cells was 2.6 mm
on 100 mesh, %	8.0	7.8	The fraction contained a large percentage of short branched thick-walled sclereids (60-70%) with smaller percentages of elongated fiberlike sclereids (10-20%) and sieve cells (10-20%)
on 150 mesh, %	4.3	4.0	The fraction contained principally short, thick-walled, branched sclereid cells (80-90%) with smaller percentages of thin-walled parenchyma and peridermal cells (10-20%) and sieve cells (5-10%)
on 200 mesh, %	5.0	2.2	The fraction contained a large percentage of thin-walled parenchyma and peridermal (principally phellem or cork cells) cells (70-80%) with a small percentage of short thick-walled sclereids (10-20%) and sieve cells (<5%)
through 200 mesh, %	33.2	43.2	The fraction contained parenchyma and peridermal (principally phellem) cells with a trace of short broken sieve cells

[a]Percentages given are on a dry weight basis.

parenchyma and peridermal cells. Figure 13 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample (50-70% outer bark) observations, it appears that, for every 100 grams of bark that is pulped, about 18 grams of solids will result. Of this 18 grams, about 5 grams (5%) of sclereidlike fibers, 2 grams (2%) of sclereids and 3 grams (3%) of sieve cells will be produced. This assumes that only material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for Douglas-fir samples collected July 22 (growing season) and November 5 (dormant season). Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 14 illustrates the zone of failure for Douglas-fir during both the growing and dormant seasons. During the growing season, wood/bark adhesion was low (3.4 kg/cm^2) and the failure zone was located in the immature newly

Figure 13. The 60-Mesh Screen (Top) Contained by Weight Sclereidlike Fibers (50-60%), Sieve Cells (30-40%) and Sclereids (10-20%). The 150-Mesh Screen (Bottom) Contained Primarily Branched Sclereids (80-90%) with Smaller Percentages of Parenchyma and Peridermal Cells (10-20%) and Sieve Cells (5-10%). Magnification — 35X

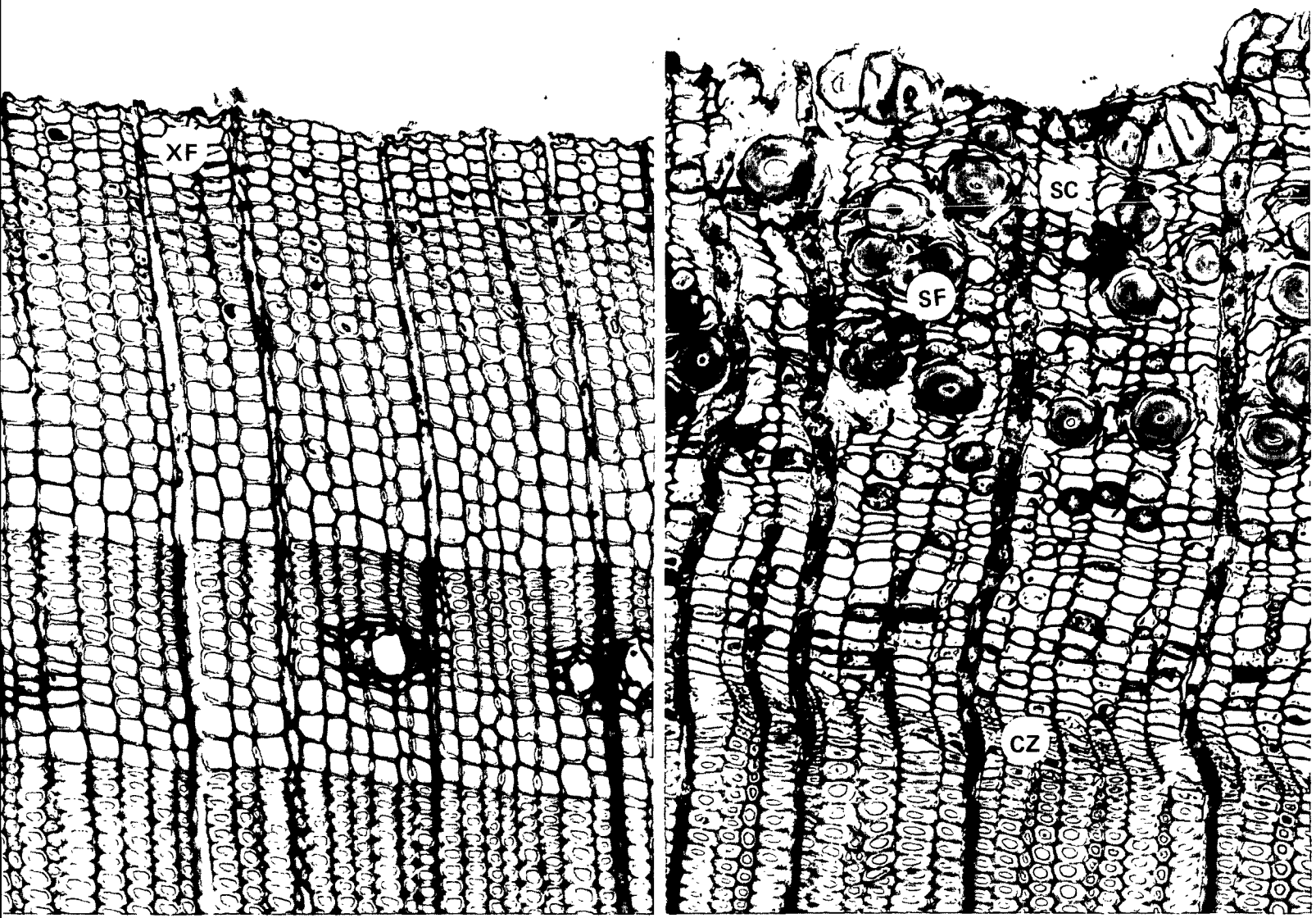

Figure 14. Illustrated Is the Douglas-fir Failure Zone for Both the Growing Season (Left) and Dormant Season (Right). The Growing Season Failure Zone Was Located in the Immature Newly-Formed Xylem Fibers (XF) Immediately Adjacent to the Cambium Zone. During the Dormant Season, the Failure Zone Moved to the Inner Bark Between the Sieve Cells (SC) and Fiberlike Sclerenchyma (SF) Approximately 1 mm from the Cambium Zone (CZ). Magnification — 125X

formed fibers (xylary initials) immediately adjacent to the cambium zone. During the dormant season, wood/bark adhesion increased to 8.0 kg/cm^2 and the failure zone was located in the inner bark (secondary phloem) between sieve cells and fiberlike sclerenchyma cells approximately 1 mm from the cambium.

As a result of measurement data taken on the species included in Appendix Table XXVII and the measurement data reported in Progress Report One, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Compression debarking was tried on Douglas-fir chips (49) in an effort to separate and segregate wood and bark. Through compression debarking and drubbing (use of tumbler with internal impact hammers), up to 92% wood recovery can be anticipated with a bark content of 7.9%. A steaming pretreatment increased wood losses in Douglas-fir and its use was not recommended.

As mentioned earlier, several approaches were tried with hardwoods in Project 2929 to reduce adhesion that might have some promise with softwoods. They included chemical, thermal, and biological methods. These techniques have

not been tried on Douglas-fir by the authors of this report but may be worthy of consideration under specific mill situations. They are discussed in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and toughness tests made on the wood and bark of Douglas-fir. Relatively small differences were obtained in bark strength between inner and outer bark. However, there was a considerable amount of difference between inner and outer bark and between wood and outer bark in toughness. Values obtained for Douglas-fir inner bark toughness were as high as those obtained for quaking aspenwood. This suggests that it may be possible to

remove most of the outer bark by hammermilling and screening procedures. Appendix Table XXVIII summarizes the bark strength values for Douglas-fir and includes a number of other species for comparison purposes.

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF DOUGLAS-FIR[a]

Material	Strength	Toughness
Wood	--	0.44
Inner bark	5.8	0.32
Outer bark	3.0	0.03

[a]Determinations made on two different trees.

Summarized in Table XVII are the results of the hammermilling tests run on Douglas-fir wood and bark. Hammermilling, followed by screening, can be expected to result in only a very moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 4% loss in wood and a 28% reduction in bark. Most of the bark lost was outer bark, confirming the bark toughness measurements. Figure 15 illustrates the effect of hammermilling on wood and bark of Douglas-fir. Perhaps part of the value of hammermilling for this species would be in separating inner from outer bark so as to make other wood/bark segregation techniques effective. Also, screening procedures might be employed that take advantage of configuration differences between wood and bark (24,25) seen in Fig. 15. This technique might look even more attractive for trees with higher amounts of outer bark.

TABLE XVII

SUMMARY OF HAMMERMILLING TEST ON DOUGLAS-FIR

Tree No.	Type Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-23	Bark	23	34	16	6	6	15	Larger mesh screens contained equal proportions of inner and outer bark. More outer bark on smaller screens
	Sapwood	50	43	5	2	1	<1	
	Heartwood	44	46	6	2	1	1	
3212-24	Bark	28	31	13	5	5	18	Slightly more inner than outer bark on larger mesh screens. Increasing amount of outer bark on smaller-mesh screens
	Sapwood	50	40	6	2	1	1	
	Heartwood	46	41	8	2	1	2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

WATER-FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water-flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip-washing procedures are employed. Earlier investigations into water-flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

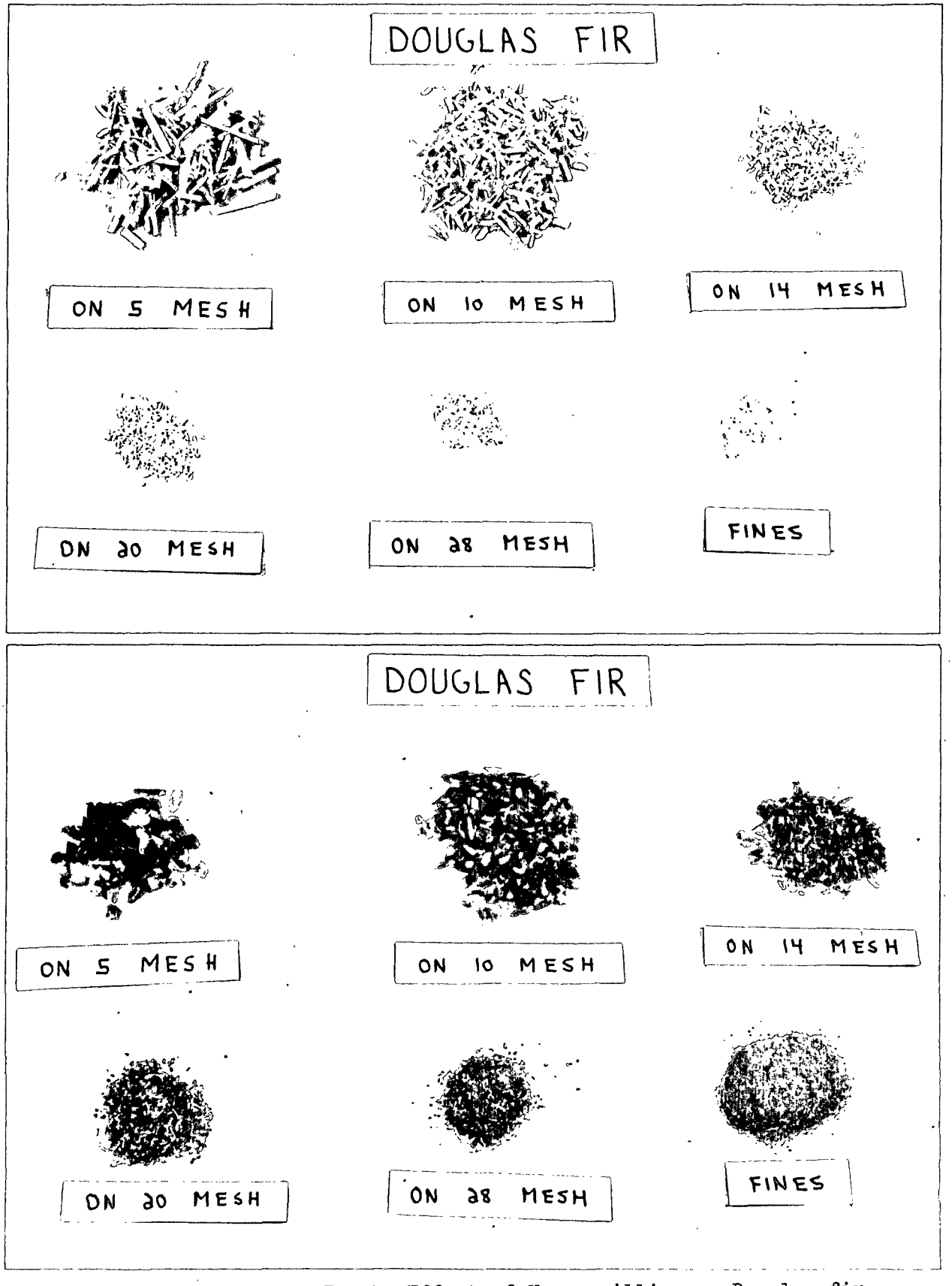

Figure 15. Illustrated Is the Effect of Hammermilling on Douglas-fir Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water-flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell-time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two Douglas-fir trees (IPC 3212-23 and IPC 3212-24) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The outer bark for 3212-24 appeared somewhat lower in density than the inner bark. No clear-cut trends in inner and outer bark density could be determined for the other Douglas-fir examined, 3212-23.

Figure 16 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

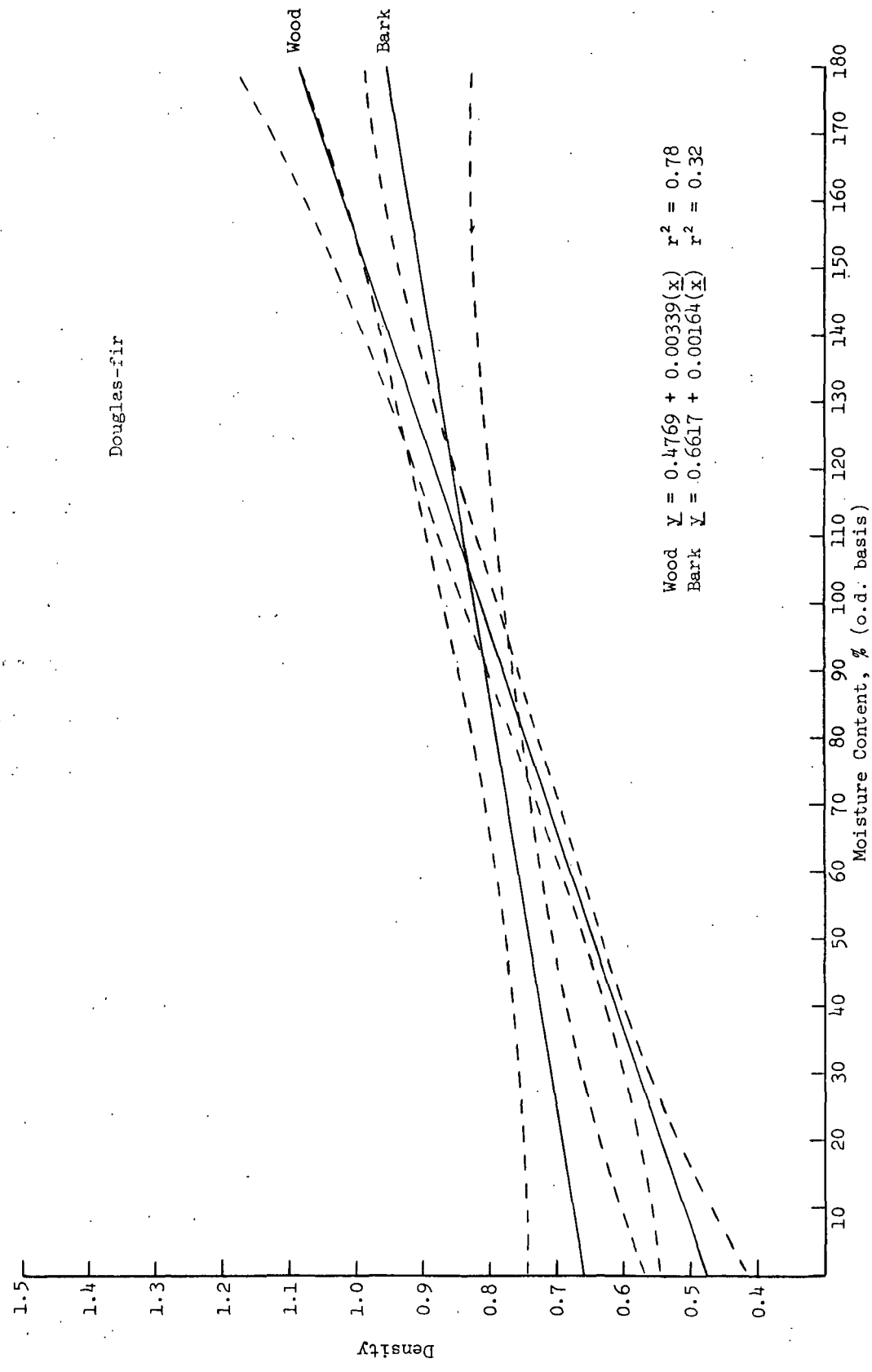

Figure 16. Illustrated Is the Relationship Between Basic Density and Moisture Content of Douglas-fir. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

least squares regression line through the data.* The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water-flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that separation through water flotation would be difficult to achieve. The densities of the wood and bark are too close at various moisture contents for effective segregation. Robins (26), using the Cartesian Diver principle, reported only fair segregation for Douglas-fir wood and bark chips. In his test, the bark input was 14.04%, the final bark output was 3.19% and only 24.15% of the total wood was recovered. He felt that if a polymer solution could limit water absorption of the wood, higher pressure would reduce bark output and raise total wood recovery.

Segregation work was also done with Douglas-fir in Institute Project 2977. Douglas-fir wood and bark chips were subjected to steam pressure of 15 psi and then floated on water at 22°C. Wood recovery varied between 75-90% with 4-11% bark contamination from an original mixture of 75% wood and 25% bark. Two factors which had an adverse influence on flotation were the buoyancy of the heartwood which remained floating with the bark and the tendency of the inner bark to sink with the wood. It also appeared that, if the inner bark could be

*Although the r^2 value for Douglas-fir bark of 0.32 (r = 0.568) is less than for the other species tested to date, the linear relationship shown is highly significant (1% level of probability).

separated from the outer bark through hammermilling or a similar technique and then the wood and bark floated, the inner bark could be removed first as sinkers and the wood later as the inner bark tends to take up water faster than the wood.

As discussed earlier, with conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also, the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity. These factors would tend to make water-flotation segregation results with conventional chips even worse than is indicated here.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell-time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XVIII summarizes the results for Douglas-fir. As was expected from the basic density results, both the bark and wood of Douglas-fir tended to float, probably due to both a similarity in density and a similarity (very slow) in moisture uptake. In all cases, as shown in Table XVIII, no wood and very little bark sank within the 4-hour time limit. Increasing the moisture content at the start of the test would very likely increase the amount of inner bark that sinks but would be of very little use in effecting satisfactory segregation.

DATA INTERPRETATION

The bark of Douglas-fir is the only one in this report that contains any fiber. However, the fiber is sclereidlike and extremely stiff and its usefulness in paper would be limited mainly to acting as filler. Short, branched, thick-walled sclereids were also found in the two samples of Douglas-fir bark pulped at the Institute although Chang (46) does not report them in his description of Douglas-fir bark. Micropulping Douglas-fir bark composed of 50-70% outer bark indicated that for every 100 grams of bark that is pulped, 18 grams of solids would result. Retained after being screened would be 5 grams of sclereidlike fibers, 2 grams of sclereids and 3 grams of sieve cells.

Considering the dirt, equipment wear, increased chemical use, etc., involved in pulping bark, it appears desirable to remove at least part of the bark. Segregation through water flotation does not appear promising due to similarities in specific gravity and basic density at various moisture contents of Douglas-fir wood and bark. Compression debarking, however, has some merit, achieving 92% wood recovery with 8% bark contamination (49).

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR DOUGLAS-FIR[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-23 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC3212-23 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-23 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	3.2	96.8
IPC 3212-24 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-24 Heartwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-24 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

It also appears possible to separate as much bark from the wood as possible through the action of the chipper, screen, hammermill the fractions high in bark and then rescreen. Hammermilling followed by screening resulted in a 4% loss in wood and a 28% reduction in bark in IPC tests. It is possible that improvements in screening (24,25) could be made that would take advantage of shape differences in Douglas-fir wood and bark chips after hammermilling.

RELATED LITERATURE

Most of the literature reviewed for Douglas-fir has been cited in the discussion on the species. Two papers previously cited that give further information of interest include one by Smith and Kozak (38) on moisture content and bark thickness and also a paper by Cassens (43), which discusses the shear strength and swelling properties of Douglas-fir. The article by Hall (47) and the proceedings of a conference on converting bark into opportunities (36) contain discussions on uses for Douglas-fir bark.

BARK AND WOOD PROPERTIES OF WESTERN HEMLOCK
(Tsuga heterophylla)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

One of the major timber-producing species in the Pacific Northwest, western hemlock grows from the Kenai Peninsula in Alaska to northwestern California. Extensive, nearly pure forests occur in the humid coastal regions of southeastern Alaska, British Columbia, Oregon and Washington. The range extends eastward along the United States-Canada border from northeastern Washington to northwestern Montana and includes a large central area of British Columbia.

Quite tolerant throughout life, western hemlock grows on a variety of soils but develops best on deep, internally well-drained soils with high rainfall conditions and at elevations of sea level to 2000 ft. The largest trees are found on moist porous soils where annual precipitation is at least 70 inches. Tree heights vary from 125-175 ft and diameters 2-4 ft. An abundance of both soil and atmospheric moisture is essential for rapid growth.

WOOD AND BARK MORPHOLOGY

Wood

Western hemlock, with a fine uniform texture and usually straight grain, has a light yellowish-brown sapwood with an indistinct heartwood. Growth rings are distinct with a more or less gradual transition from early-wood to latewood. The earlywood usually occupies two-thirds or more of the annual ring and is lighter and less dense than latewood. Rays are very fine and, although resin canals are usually absent, longitudinal strands of traumatic resin cells or wound canals sometimes occur sporadically in tangential

lines in widely separated rings and appear as dark streaks along the grain. Composing 91.2% of the wood volume, the fiber tracheids average 30-40 μm in diameter and 4.2 mm (1.8-6.0 mm) in length. Longitudinal parenchyma are very sparse or lacking. Rays, accounting for approximately 8-10% of the wood volume, are usually uniseriate and 1-16 cells in height. Ray tracheids are present, usually restricted to one row on the margins of the ray.

Bark

Mature western hemlock bark, reddish-brown with a purplish-red hue where the periderm is exposed, is deeply fissured with rather large and firm scales. Inner bark, about 1/4-inch thick, has a yellowish hue when freshly cut, turning pink after exposure. Diffused sclereid groups, visible to the naked eye, begin very close to the cambium and occur throughout the inner bark. Western hemlock bark has long been recognized for its tannin yield. The inner and outer bark each comprised approximately half the bark sample by weight for the trees tested as part of this project. Figure 17 illustrates the appearance of the major elements of the wood and bark of western hemlock. Appendix Table XXVI describes the trees used in this study.

Anatomical Structure of Young Bark

Bark of the young tree consists of an epidermis, periderm, narrow cortex and secondary phloem of sieve cells and phloem parenchyma. The epidermal cells have scattered hairs and often contain "resinous" substance. The phellem cells of the periderm are thin-walled and suberized. Cortex cells, thick-walled and collenchymalike, are aligned compactly in more or less regular rows at the outer margin of the cortex. Some of the cortical cells may become "lignified" as the bark grows older. Scattered sclereids appear at the outer part of the

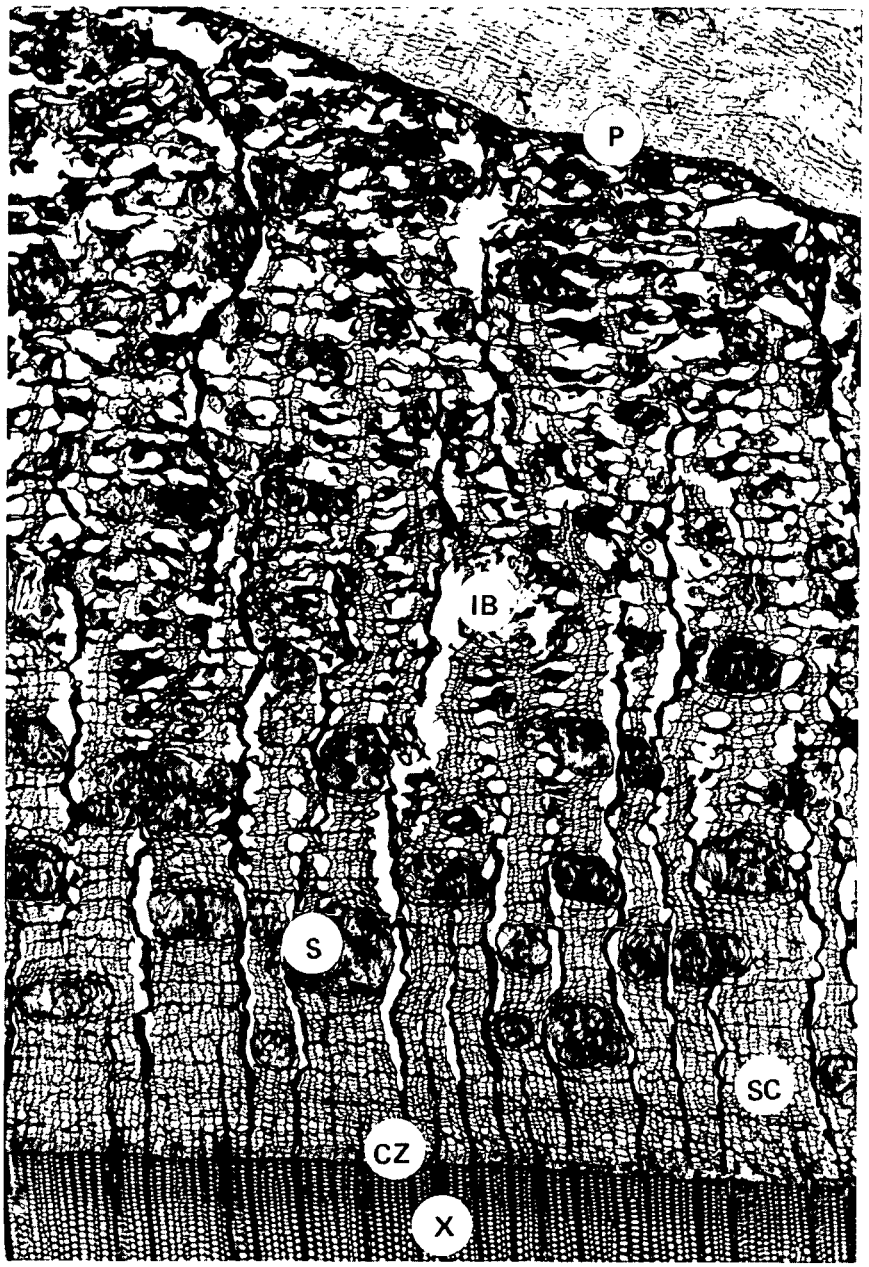

Figure 17. Illustrated Is the Appearance of the Major Elements in the Inner Bark of Western Hemlock Including the Xylem (X), Cambium Zone (CZ), Sieve Cells (SC), Sclereids (S), Inner Bark (IB) and Periderm (P). Groups of Thick-Walled Sclereids in the Proximity of the Cambium Are Characteristic of Western Hemlock Barks. The Periderm Is Composed Principally of Thick-Walled Phellem Cells. The Outer Bark (Not Shown) Consists of Alternating Bands of Periderm (P) and Isolated Secondary Phloem. Magnification — 35X

secondary phloem which has the general arrangement of the mature bark. Intercellular resin passages appear distinctly only in young bark.

Anatomical Structure of Mature Bark

Western hemlock rhytidome, usually 1/4-3/4 inch thick, is composed of alternate layers of expanded parenchyma and sclereids isolated from the inner bark by the successive bands of periderm. The rather broad periderm consists of 2-3 layers of phelloderm, a layer of phellogen, and 10-20+ layers of phellem. The thin-walled phellem cells are rectangular in cross section, usually about 20 μm in radial diameter, 30 to 50 μm in tangential diameter, and 20-50 μm in height. Phelloderm cells are slightly larger with comparatively thicker walls.

Sieve cells, sclereids, parenchyma strands and uniseriate rays form the secondary phloem of western hemlock. Sieve cells, aligned in radial rows of 3-7, are rectangular in cross section, 10-15 and 15-30 μm in radial and tangential dimensions, respectively, and vary from 1.5-4 mm in length. This shape is maintained only within approximately 20 cells of the cambial region. Beyond this area, the sieve cells become obliterated by the sclereid groups. Diffused small groups of sclereids are distributed from close to the cambium throughout most of the inner bark. Individual cells in the sclereid groups are branched and twisted, about 400 μm long, and contain resinous substances. Interrupting the radially aligned sieve cells, parenchyma strands are aligned more or less in continuous tangential lines. Individual cells, when newly formed, are approximately the size and shape of sieve cells in cross section, but become radially expanded and enlarged nearer the outer bark. Phloem rays, mainly uniseriate, are generally 10-15 cells high, approximately 300 μm, but may reach twice that height. Ray cells are 30-50 μm in radial dimension and about 10 μm high close to the cambium, but, like parenchyma, expand at the

outer part of the inner bark. Marginal or albuminous cells, about 2-3 times the height of ordinary ray cells, are present at almost every ray close to the cambium.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and sclereids are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Whenever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Specific gravity of wood of western hemlock has been measured by a number of individuals but there does not appear to be much data available on bark. Table XIX summarizes the information available, and whenever possible, information on bark has been separated into inner and outer bark. Specific gravity is most often expressed in terms of ovendry weight over green volume. It should be noted that several of the values in Table XIX are ovendry weights divided by ovendry volumes.

The specific gravity of the total (inner + outer) bark of western hemlock appears somewhat higher than that of the wood, although not significantly so. Our limited data do not show any clear-cut trends in the relationship of inner to outer bark specific gravity. Both trees sampled as part of this

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

project (3212-21 and 3212-22) exhibited higher inner than outer bark specific gravity but Smith and Kozak (38) reported a reverse trend. Overall values suggested for use in species comparisons are 0.40 for wood and 0.46, 0.45 and 0.45 for inner, outer and total bark.

TABLE XIX

WESTERN HEMLOCK SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood		Bark				
Average	Range	Inner	Outer	Total	Range	References and Remarks
0.41				0.44		Smith, J. H. G. (39)
0.42	0.30-0.52					Maeglin & Wahlgren (50)
0.38						Wood Handbook (7)
0.38						Besley (U.S.) (10)
0.41						Besley (Canada) (10)
		0.45	0.56			Smith & Kozak (38)
0.38						Isenberg (11)
0.41		0.49	0.44	0.49		IPC 3212-21
0.38		0.43	0.36	0.40		IPC 3212-22
0.42						Brown, et al. (41)
0.47[a]						
0.44[a]						Isenberg (11)
				0.59[a]		Harkin & Rowe (14)

[a]Ovendry weight/ovendry volume.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected

to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Table XX summarizes information found on extractives levels of western hemlock and includes the two trees sampled as part of this project. Western hemlock wood is very low in extractives and a level of 1.6% is suggested for use in between-species comparisons. Extractives work done on western hemlock bark in this project showed an average level of 11.7%. This is a moderate level of extractives and pulping of western hemlock bark should not result in serious extractives problems.

TABLE XX

WESTERN HEMLOCK ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	1.6	Rydholm (33)
Wood	1.6	Isenberg (11)
Bark	10.2	IPC 3212-21
Bark	13.2	IPC 3212-22

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these

cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of western hemlock having an effect on the pulp are sieve cells and sclereids.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. This problem might especially arise with the thick-walled, branched groups of sclereids and the larger, individual sclereid cells. Estimates made of IPC macerated bark samples suggest that sclereids make up 18-23% of the total bark weight. These levels are higher than the levels found in any of the other conifers examined in this report.

There are no phloem fibers in western hemlock bark but there are fairly large quantities of sieve cells. These cells could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, what they would contribute to sheet strength. Sieve cells, when subjected to beating, probably would not fibrillate to any appreciable extent. The coarseness value of western hemlock wood pulp fibers would probably be 5-6 times greater than the coarseness value of the thin-walled sieve cells. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Worster and Vinje (51), in pulping undebarked western hemlock tops and branches, obtained pulps with lower strength properties than the bole and with shorter, finer fibers. The screened yields were approximately 38%. Other results included higher pulping chemical requirements, lower brightness and higher dirt count.

As a check on pulp yield and the nature of the material produced from western hemlock, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXI summarizes the results of this investigation. Micropulping of western hemlock bark resulted in a yield of 34 to 38% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the sieve cells and many of the sclereids. The on 150-mesh screen had a high percentage of sclereids. The on 200-mesh and through 200-mesh screens contained mainly sclereids and peridermal cells. Figure 18 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 36 grams of solids will result. Of this 36 grams, about 13 grams (13%) of sieve cells and 11 grams (11%) of sclereids will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

TABLE XXI

WESTERN HEMLOCK MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-21	Sample No. 2312-22	Remarks[a]
Yield, % solids	38.0	33.5	
Fraction			
on 60 mesh, %	34.4	50.4	The fraction contained a mixture of sieve cells (70-80%) and groups of thick-walled sclereids (20-30%). The average length of the sieve cells was 2.55 mm
on 100 mesh, %	23.6	18.2	The fraction contained principally branched thick-walled sclereid cells (90-95%), with a small percentage of sieve cells (5-10%) and a trace (<1%) of parenchyma and peridermal cells
on 150 mesh, %	16.6	15.2	The fraction contained principally the coarse thick-walled sclereid cells (>95%) with a small percentage of sieve cells (<5%) and a trace of parenchyma and peridermal cells (<1%)
on 200 mesh, %	3.6	4.2	The fraction contained a large percentage of sclereids (80-90%) with small percentages of parenchyma and peridermal cells (5-10%) and sieve cells (<5%)
through 200 mesh, %	21.8	12.0	The fraction contained percentages of small individual sclereid cells (50-60%) perenchyma and peridermal cells (40-50%) with a small percentage (<5%) of sieve cells

[a]Percentages given are on a dry weight basis.

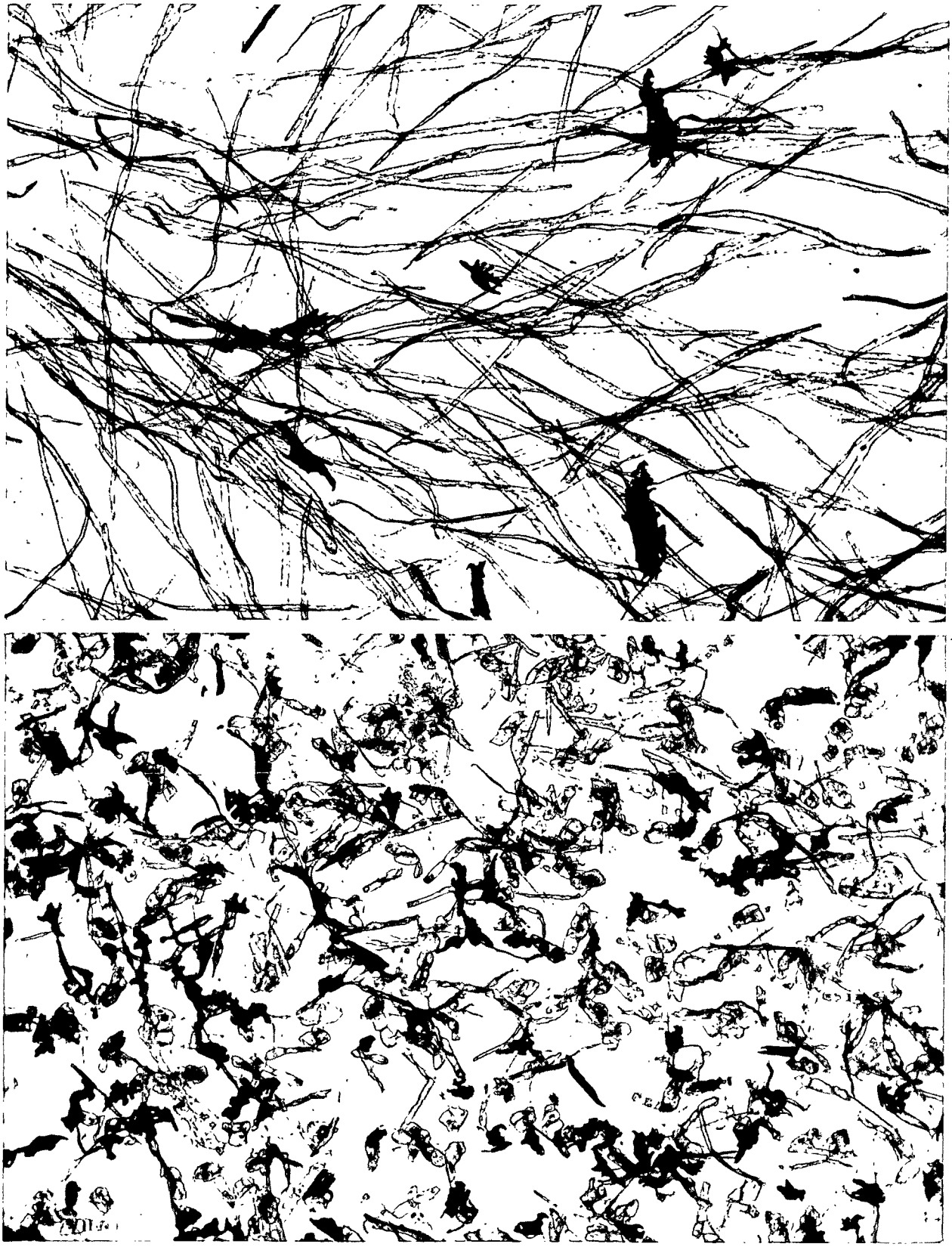

Figure 18. The 60-Mesh Screen (Top) Contained Primarily Sieve Cells (70-80%) and Thick-Walled Sclereids (20-30%). The 150-Mesh Screen (Bottom) Contained by Weight Mostly Thick-Walled Sclereid Cells (> 95%). Magnification — 35X

Wood/bark adhesion values were measured for western hemlock samples collected July 22 (growing season) and November 5 (dormant season). Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 19 illustrates the zone of failure for western hemlock during both the growing and dormant seasons. During the growing season, wood/bark adhesion was low (3.6 kg/cm^2) and the failure zone was located in the newly formed fibers (xylary initials) in the cambium zone. During the dormant season, wood/bark adhesion increased to 8.2 kg/cm^2 and the failure zone was located in the dormant cambium zone in the cells immediately adjacent to the last-formed fully mature xylem tracheids of the current season's growth increment. This location of the dormant season failure zone differs from that of other tree species. Normally, failure occurs in the inner bark.

As a result of measurement data taken on the species included in Appendix Table XXVII and the measurement data reported in Progress Report One, it is clear that dormant season wood/bark adhesion for most species is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and a lack of phloem fibers seem to be associated with low dormant season wood/bark adhesion and low bark strength. This general approach toward wood/bark adhesion does not appear to apply to western hemlock.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips).

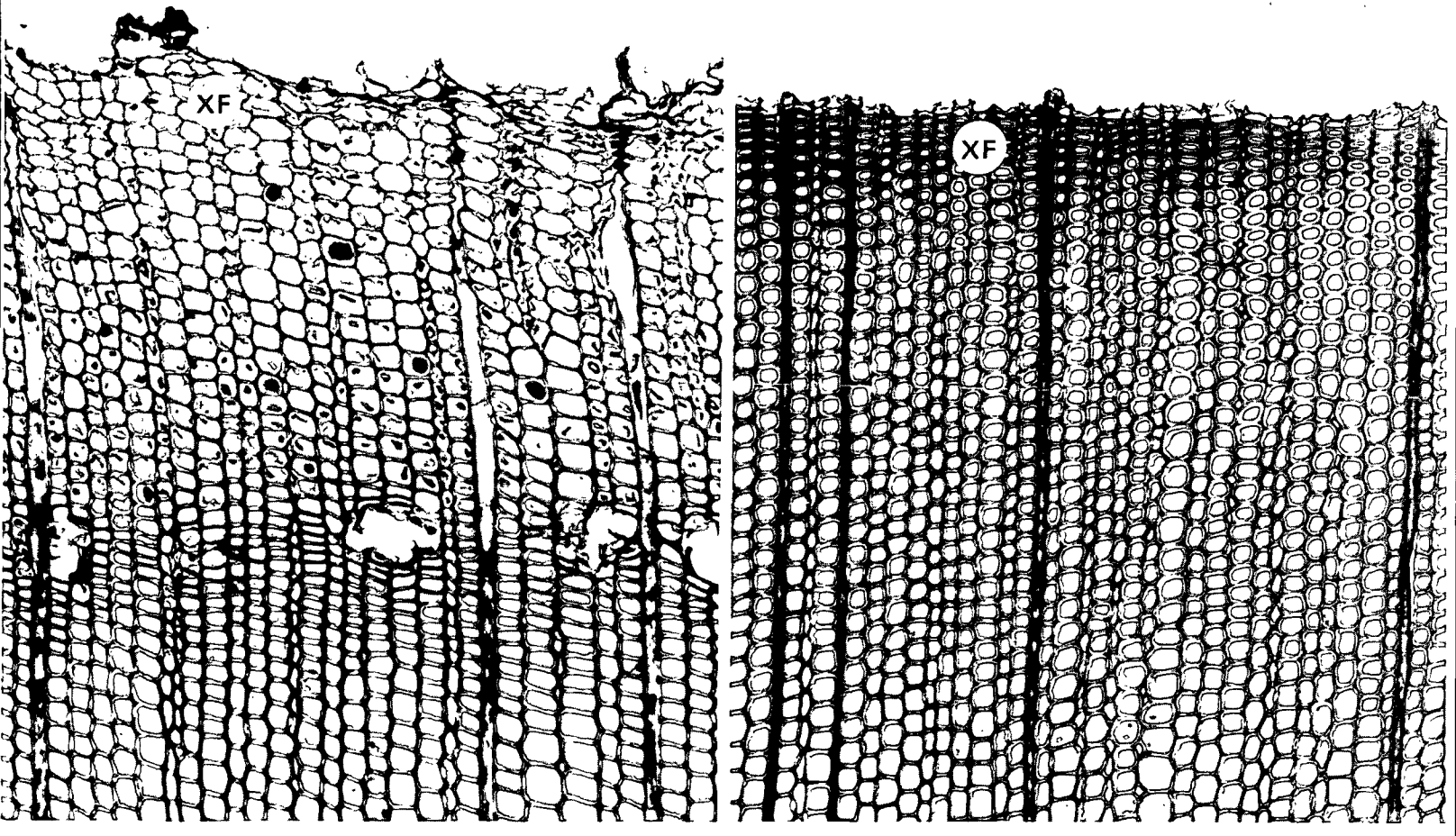

Figure 19. Illustrated Is the Western Hemlock Failure Zone for Both the Growing Season (Left) and Dormant Season (Right). During the Growing Season Failure Occurred in the Newly-Formed Fibers (XF) in the Cambium Zone. During the Dormant Season Failure Was Located in the Dormant Cambium Zone in the Cells Immediately Adjacent to the Last-Formed Fully Mature Xylem Fibers (XF) of the Current Season's Growth Increment. Magnification — 125X

Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Western hemlock chips were subjected to compression debarking (49) in an effort to separate and segregate wood and bark. Through compression debarking and drubbing (use of tumbler with internal impact hammers) up to 92.4% wood recovery can be anticipated with a bark content of 4.3%. A steam pretreatment was of some help in increasing the wood recovered in the large chip size classes but did not add significantly to the results for the small chip classes.

As discussed in preceding sections, several of the approaches that were tried with hardwoods in Project 2929 to reduce adhesion might have some promise with softwoods. They included chemical, thermal and biological methods. These techniques have not been tried on western hemlock but may be worthy of consideration under specific mill situations. They are discussed in the section on Between-Species Comparisons.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step

in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and toughness tests made on the wood and bark of western hemlock. Relatively small differences were obtained in bark toughness between inner and outer bark of western hemlock. Toughness test values were also relatively low for western hemlock wood. The bark strength values obtained for western hemlock inner bark were moderate. No tests were able to be made on the outer bark because the bark was too fissured and enough surface area was not available for testing. Toughness and strength tests indicate that hammermilling or a similar technique might not work as well on this species. The low bark strength and toughness values obtained are probably a result of the lack of fibers and presence of sclereids in the bark. Appendix Table XXVIII summarizes the bark strength values for western hemlock and includes a number of other species for comparison purposes.

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF WESTERN HEMLOCK[a]

Material	Strength	Toughness
Wood	--	0.22
Inner bark	6.0	0.12
Outer bark	--	0.10

[a]Determinations made on two different trees.

Summarized in Table XXIII are the results of the hammermilling tests run on western hemlock wood and bark. Hammermilling, followed by screening can be expected to result in only a very moderate reduction in levels of bark. When the two trees investigated were hammermilled, and the material on the 14-mesh screen retained, the result was a 3% loss in wood and a 24% reduction in bark. Although the wood loss is extremely low, due probably to the pliable nature of the wood, the amount of bark removed is also less than for any of the species investigated so far. Figure 20 illustrates the effect of hammermilling on wood and bark of western hemlock. Perhaps part of the value of hammermilling for this species would lie in separating inner from outer bark so as to make other wood/bark segregation techniques effective. Configuration differences between wood and bark in hammermilled samples indicate improved screening techniques might improve results (24,25).

TABLE XXIII

SUMMARY OF HAMMERMILLING TEST ON WESTERN HEMLOCK

		Fraction Retained on Standard Screen[a], %						
Tree No.	Type Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-21	Bark	23	34	14	7	6	16	Larger-mesh screens contained mostly outer bark. Two-thirds to 3/4 inner bark on 28-mesh screen and in fines
	Wood	56	36	5	1	<1	1	
3212-22	Bark	32	35	12	5	4	11	Nearly all outer bark on larger-mesh screens. Two-thirds to 3/4 inner bark on 28-mesh screen and in fines
	Wood	50	41	6	2	1	1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

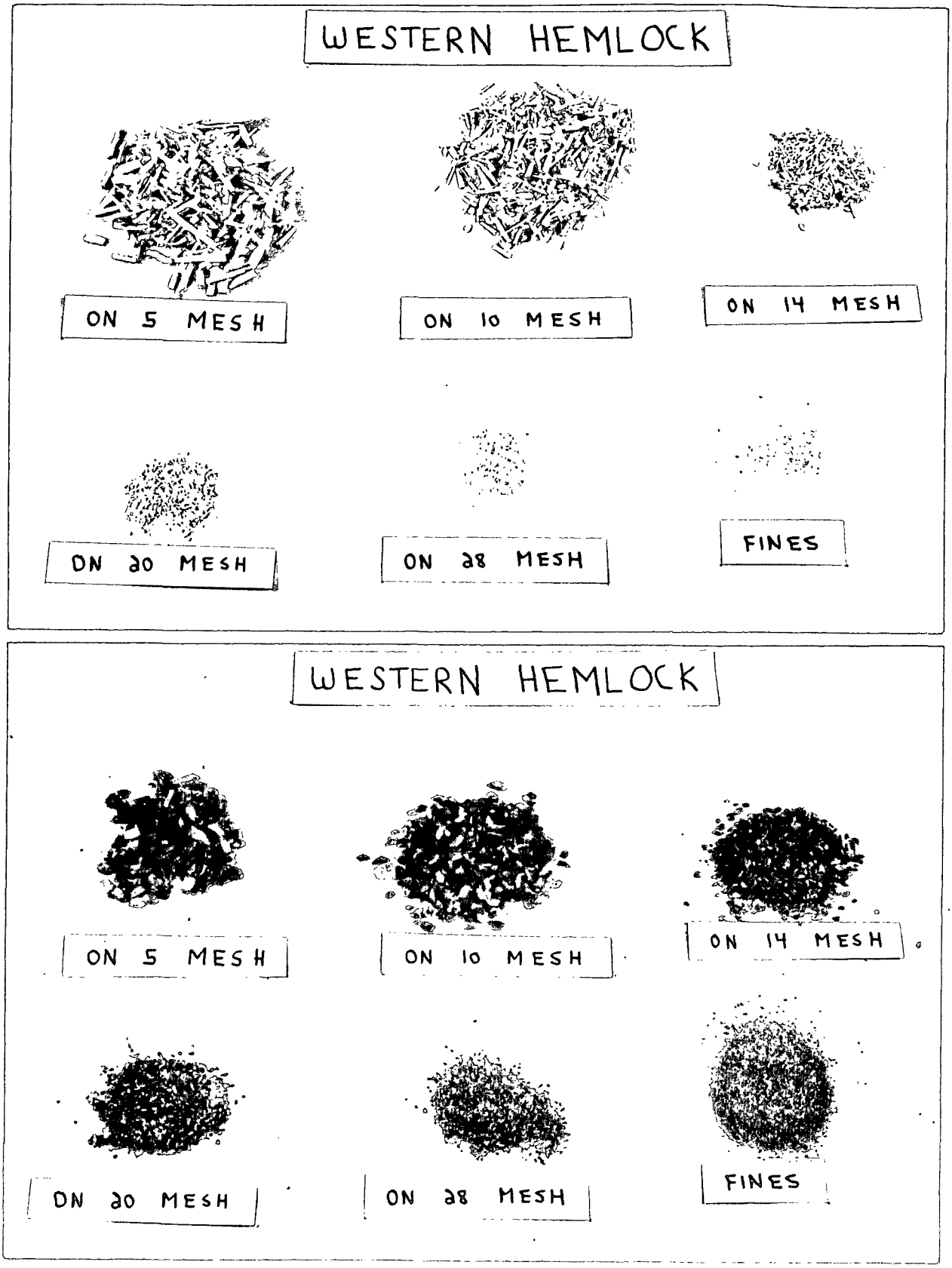

Figure 20. Illustrated Is the Effect of Hammermilling on Western Hemlock Wood (Top) and Bark (Bottom). Larger-Mesh Screens Contained Mainly Outer Bark

WATER-FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is also expected to be important when certain types of chip-washing procedures are employed. Earlier investigations into water-flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water-flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell-time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two western hemlock trees (IPC 3212-21 and IPC 3212-22) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in the terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner and outer bark of western hemlock appeared to have approximately the same density.

Figure 21 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water-flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture, and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that, like Douglas-fir, segregation would be difficult to achieve. The wood and bark of western hemlock are very close in density at various moisture contents. Robins (26) reported poor segregation (bark output of 7.78% from an original bark input of 13.88% with 33.94% wood recovery) of western hemlock bark and wood chips but attributed it to working with a decomposing sample. He felt segregation should be possible as he found a density gradient between the bark and wood of western hemlock which centered around a density of one. He concluded that using a freshly cut sample at a pressure of 40 psig would cause segregation to take place.

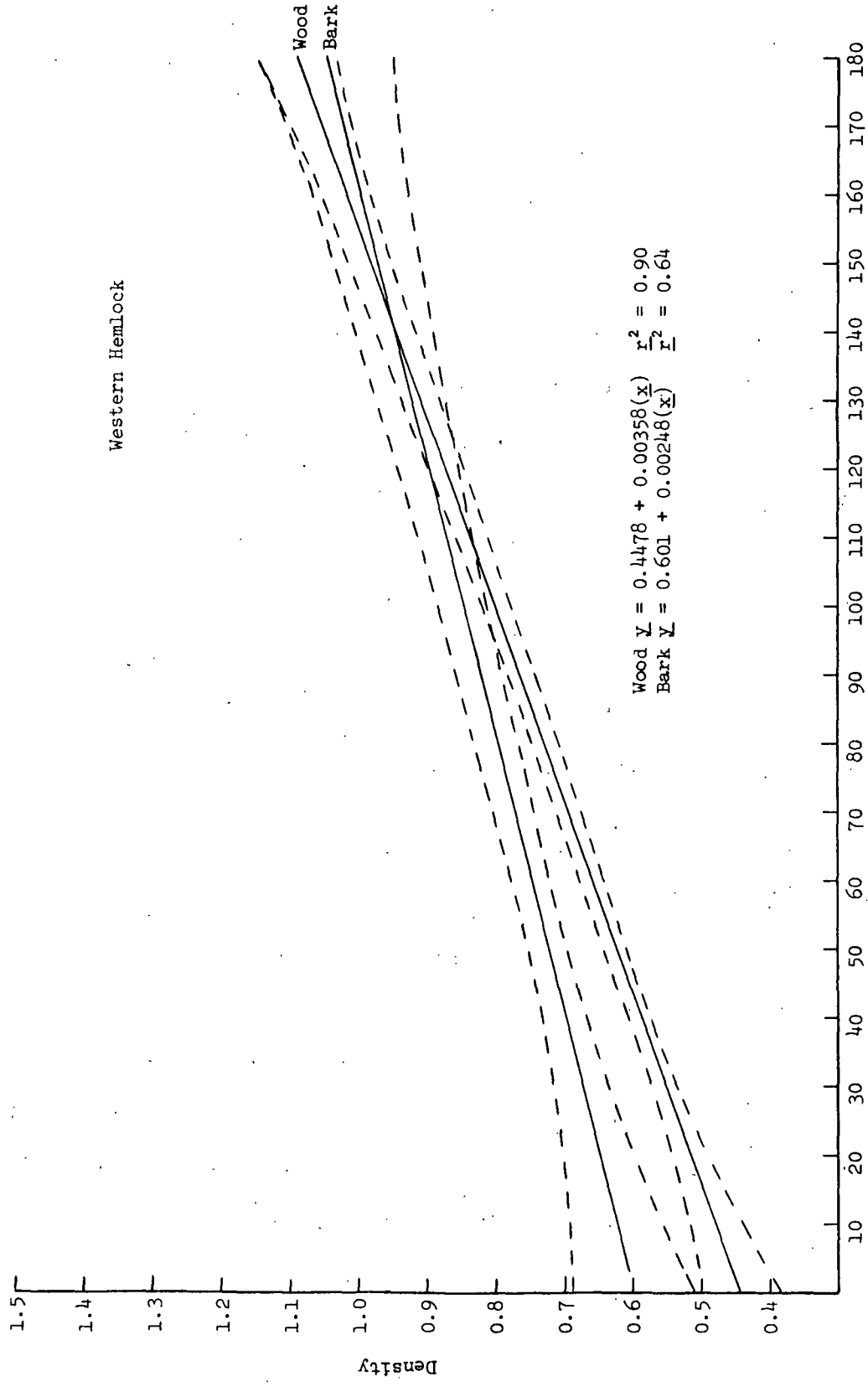

Figure 21. Illustrated Is the Relationship Between Basic Density and Moisture Content for Western Hemlock. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

His results do not agree with the results of our density determinations which show western hemlock wood and bark to be too close in density for effective segregation. Results obtained in a previous project at the Institute (Project 2977) also showed that the flotation characteristics of western hemlock wood and bark are too similar to allow development of a simple liquid flotation segregation system. There is a possibility that, if inner bark could be separated from outer bark, the inner bark, which sinks immediately, could be removed, and the wood recovered in later baths as either sinkers or floaters.

As discussed earlier, with conventional chips not all bark chips are total bark (inner + outer bark). Some are all outer bark, some are mostly inner bark and some have wood attached. Also the moisture content of outer bark is often less than that of inner bark when conventional chips are used. Air entrapment in bark can reduce bark specific gravity and the presence of reaction wood and stain can greatly increase wood specific gravity. These factors would tend to make water flotation segregation results with conventional chips even worse than is indicated here.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are

similar, and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Time required for chip samples to sink decreases as the sample moisture content at the start of the trial increases.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell-time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XXIV summarizes the results for western hemlock. Dwell-time results confirmed conclusions drawn from the density determinations. Both the wood and bark of western hemlock tended to float at this moisture content due to similar low densities and a similarity (very slow) in moisture uptake. In all cases, as shown in Table XXIV, all the wood and bark was still floating after four hours.

TABLE XXIV

SUMMARY OF DWELL-TIME RESULTS FOR WESTERN HEMLOCK[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-21 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-21 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-22 Sapwood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-22 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

The bark of pulpwood-size western hemlock, although relatively thin and composed of similar amounts of inner and outer bark, has no true fiber in the bark and appears to be a source of "sclereid" problems. Most of the sclereids are located in the outer bark but scattered groups appear throughout the inner bark and are in fairly large numbers in the outer part of the inner bark. Estimates made on macerated samples indicate these short, thick, heavily lignified (sometimes branched) cells make up 18-23% of the total bark weight.

Micropulping of western hemlock bark, followed by examination of the material retained on the 60- and 100-mesh screens, indicates for every 100 grams of bark pulped, 13 grams (13%) of sieve cells and 11 grams (11%) of sclereids will be produced. Approximately half of the sclereid cells originally present were cooked to the point that they separated into small enough groups that they passed through the 60- and 100-mesh screens and could be expected to be removed by pulp screening and washing operations. Further reductions in sclereids might be possible by beating and centricleaning procedures.

Considering the lack of true fiber and the presence of large numbers of sclereids, removal of at least the outer bark of western hemlock should be given appropriate consideration. The possibility of the segregation of bark/chip mixtures does not look as promising for hemlock as for the other species described in this report. Density determinations at varying moisture contents indicate there is little chance, because of the similarity of bark and wood flotation behavior, that a simple water-flotation procedure could be used.

Compression debarking trials with western hemlock suggest that this approach is probably the most promising of the techniques presently available.

Wood recovery of 92% with about 4% bark contamination was achieved either with or without the steaming step often employed (49).

No data had been published on how well chipper action separates the bark and wood of hemlock. Because of similarities in wood density and bark thickness, western hemlock could be expected to handle much like white spruce. White spruce, because of its low density and thin bark, did not separate as well as thick-barked high-density species that were investigated.

The only other approach that seems worthy of further consideration is the use of the "screening — hammermilling — screening" procedure described earlier. Toughness tests on wood and bark suggest that this technique might not work very well because of the low toughness value obtained for hemlock wood. Wood losses, however, were quite low (3%), apparently due to the relatively soft nature of the wood. The reduction in bark level was about 24% and there is some evidence that the use of gyrating screening techniques (24,25) to take advantage of bark and wood chip configuration differences could be expected to further increase the amount of bark removed.

RELATED LITERATURE

The literature reviewed for western hemlock was cited in the discussion on the species. One article, previously mentioned, that contains information on bark thickness and moisture content is a paper by Smith and Kozak (38).

BETWEEN-SPECIES COMPARISONS

Table XXV was prepared to provide a method of quickly comparing the basic information available for selected pulpwood species. Because of the limited number of species that have been investigated to date, very few meaningful comparisons can be made. Hopefully, as more and more information becomes available, useful relationships between morphology, density, bark strength measurements, and wood/bark adhesion will emerge.

For the first eight species investigated, the conifer barks studied have had lower specific gravities than the hardwood barks. There has been no consistent pattern evident regarding levels of extractives, pulp yield or bark toughness despite large between-species differences.

The conifer barks, in addition to having lower specific gravity, have quite consistently had little usable fiber. Douglas-fir could be considered an exception to this statement; however, the Douglas-fir fibers are generally considered to be sclereidlike fibers rather than true fibers and, because they are short and thick-walled, are not expected to contribute to paper strength in any useful way.

Wood/bark adhesion during the growing season has varied little from one species to another and the zone of failure quite consistently occurred in the cambium zone or the newly formed nonlignified fibers immediately adjacent to the cambium zone. Dormant season adhesions consistently have been greater than during the growing season and, in most instances, higher for hardwoods than for conifers. Dormant season failure usually occurred in the partially mature sieve and parenchyma cells of the inner bark located just outside the

TABLE XXV

WOOD AND BARK CHARACTERISTICS OF PULPWOOD SPECIES

Characteristic	Quaking Aspen	Sugar Maple	White Birch	Northern Red Oak	Loblolly Pine	Slash Pine	Douglas-fir	Western Hemlock
Specific gravity (ovendry wt./green volume)								
Wood	0.38	0.59	0.49	0.56	0.45	0.54	0.43	0.40
Whole bark	0.50	0.54	0.56	0.65	0.33	0.35	0.41	0.45
Inner bark	0.40	0.69	0.57	0.53	0.29	0.34	0.42	0.46
Outer bark	0.55	0.49	0.54	0.71	0.34	0.36	0.40	0.45
Extractives, %								
Wood	3.0	1.0	4.0	4.5	3.0	3.3	4.0	1.6
Bark	15	6	17	11	8.5	8.4	16.4	11.7
Density at 100% moisture (green wt./green volume)								
Wood	0.79	1.24	1.01	1.06	0.88	1.10	0.815	0.80
Bark	1.15	1.08	1.16	1.18	0.57	0.72	0.825	0.85
Pulp yield, % (bark)	33.8	33.9	36.3	28.4	23.6	23.6	17.6	35.8
Usable bark fiber, %[a]	10	3	0	5	0	0	5	0
Sclereids remaining, %[a]	1	0.2	0.7	0.2	0	0	2	11
Fiber location[b]	IB	IB	--	IB	--	--	IB-OB	--
Sclereid location[b]	IB	IB	IB	IB	--	--	IB-OB	IB-OB
Wood/bark adhesion, kg/cm^2								
Growing season	6.4	5.8	5.1	2.5	5.8	3.5	3.4	3.6
Dormant season	11.4	10.1	12.0	8.4	--	9.1	8.0	8.2
Bark strength, kg/cm^2								
Inner bark	9.0	1.4	1.6	2.1	3.7	6.4	5.8	6.0
Outer bark	4.9	4.7	9.8	4.6	3.2	5.2	3.0	--
Toughness								
Inner bark	0.18	0.21	0.09	0.12	0.07	0.06	0.32	0.12
Outer bark	0.10	0.10	0.11	0.16	0.04	0.08	0.03	0.10
Sapwood	0.30	0.62	0.44	0.42	0.36	0.35	0.44	0.22
Hammermilling[c]								
Bark removed, %	34	29	38	34	34	36	28	24
Wood loss, %	5	5	6	10	6	5	4	3

[a]Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.

[b]Major proportion located in either the inner bark (IB) or outer bark (OB).

[c]Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

cambium zone. High wood/bark adhesion in hardwoods often is associated with large numbers of phloem fibers in the inner bark.

Breaking the bond between wood and bark (separation) is an important first step in any segregation procedure. A very practical way of separating bark and wood during the growing season, and in some instances during the dormant season, is through the action of the chipper. Arola (21) working with northern hardwoods, found that chipper action during the growing season gave better results than during the dormant season with less than 2% tight bark remaining on the chips from 4-6 and 8-inch diameter bolts. Erickson (22), working with maple, reported at least 96% separation during chipping throughout the year. He also found better separation with winter-cut frozen wood over unfrozen bolts although more fines resulted.

Despite the consistent location of the wood/bark failure zone there are, particularly during the dormant season, major differences between species in the ability of a chipper to cause separation. Preliminary investigations (Project 2929) suggest inner bark strength and the chipper knife impact at the cambium zone are important factors. For hardwoods, and possibly some conifers, the presence of fibers and sclereids in the inner bark influence inner bark strength. Bark thickness and wood density (or frozen wood) influences chipper knife impact at the cambium zone. Chipper separation during the dormant season is expected to be least effective on thin-barked, low-density woods with fiber in the inner bark.

Reduction of wood/bark adhesion is an approach that should be considered when attempting to improve segregation procedures. Because most approaches stress reducing the adhesion in the cambium zone, only modest

between-species differences are expected in the effectiveness of different techniques. Budget limitations have prevented research on chipper action and reduction of wood/bark adhesion from being included as part of Project 3212. Earlier investigations (Project 2929) indicated that there were a number of procedures (chemical, thermal, and biological) worthy of further consideration. The use of green kraft cooking liquor at a temperature of 200°F and a treatment time of 60 min gave reduced adhesion. The main disadvantage was the high temperature and long treatment time required. Chemical treatments were also investigated by Haas and Kremers (52) and, in their work, dilute acids were effective in reducing adhesion. The principal disadvantage of this treatment was the length of time required to effect separation, the discoloration of the wood of some species, and the ineffectiveness of the treatment on dry samples.

Pressure chamber treatments also looked promising with reduced treatment time needed when temperatures were in excess of 250°F. Moist storage of chips at temperatures that encourage fungus attack of the cambium zone resulted in greatly reduced wood/bark adhesion at storage times as short as 15-20 days. Another promising approach was the use of microwave heating to create high temperatures in the moist interior of the chips. There was a moderate reduction in wood/bark adhesion at treatment times as short as one minute.

PLANS

Plans are to cover characterization of the sixteen species involved in this project in four reports. The first four species, quaking aspen, sugar maple, white birch, and northern red oak, were covered in a report issued Nov. 1, 1974. The third report, scheduled for completion the end of April, will cover white spruce, jack pine, balsam fir, and eastern cottonwood. Sweetgum, southern red oak, northern and southern sources of white oak and silver maple will be dealt with in the fourth and last report. The format of each report will be exactly the same to make the information and comparison of species as useful as possible.

ACKNOWLEDGMENTS

The authors of this report are indebted to Mr. Dale Volkman and Mr. Ted Clark of International Paper Company and Mr. William Fuller and Mr. Roger Vining of Weyerhaeuser Company for supplying the samples used in characterizing the four species covered in this report. Thanks also go to Gary Wyckoff, Brent Stewart, Dave Wautier and Sandy Berghuis for their assistance with certain aspects of the study. The authors also wish to acknowledge the help of Roger Van Eperen and John Peckham and his staff within the Division of Materials Engineering & Processes for adhesion, strength and toughness measurements and the pulping work that was carried out. Special thanks go to Shirley Verhagen for her assistance with density determinations and wood and bark morphology descriptions.

LITERATURE CITED

1. Chang, Y. P. Anatomy of common North American pulpwood barks. New York, TAPPI Monograph Series No. 14, 1954. 249 p.

2. Thode, E. F., Peckham, J. R., and Daleski, E. J. An evaluation of certain laboratory pulping methods. Tappi 44(2):81-8(1961).

3. Koch, P. Utilization of the southern pines. U.S.D.A., Forest Service, Agriculture Handbook No. 420, Vol. I, 1972. 734 p.

4. Phillips, D. R., and Schroeder, J. G. Some physical characteristics of bark from plantation-grown slash and loblolly pine. Forest Prod. J. 22(10):30-3(1972).

5. Fournier, F., and Goulet, M. Physical and mechanical properties of bark. A bibliographical study. Rech. Dep. Exploit. Util. Bois Univ. Laval Note No. 7, 1971. 44 p.

6. Zobel, B. J., Kellison, R. C., Matthias, M. F., and Hatcher, A. V. Wood density of the southern pines. North Carolina Agricultural Experiment Station, Tech. Bul. No. 208, May 1972. 56 p.

7. U.S.D.A., Forest Service, Forest Products Laboratory. Wood handbook. Agriculture Handbook No. 72, 1955. 528 p.

8. Christopher, J. F., and Wahlgren, H. E. Estimating specific gravity of south Arkansas pine. U.S.D.A., Forest Service Research Paper SO-14, 1964. 10 p.

9. Wahlgren, H. E., and Schumann, D. R. Properties of major southern pines: Part I: Wood density survey. U.S.D.A., Forest Service Research Paper FPL 176, 1972. 57 p.

10. Besley, L. Importance, variation and measurement of wood density and moisture. Pulp & Paper Research Institute of Canada, Tech. Report No. 489, 1966. 30 p.

11. Isenberg, I. H. Pulpwoods of United States and Canada. 2nd ed. Appleton, Wis., The Institute of Paper Chemistry, 1951. 187 p.

12. Einspahr, D. W., Peckham, J. R., and Mathes, M. C. Base lines for judging wood quality of loblolly pine. Forest Sci. 10(2):165-73(1964).

13. Renfro, J. F. Bark and cambium characteristics of pond pine (Pinus serotina Michx.) and loblolly pine (Pinus taeda L.) with special reference to fire hardiness. M.F. Thesis. North Carolina State College, Raleigh. 46 p.

14. Harkin, J., and Rowe, J. W. Bark and its possible uses. U.S.D.A. Forest Service Research Note FPL-091, Revised 1971. 56 p.

15. Martin, R. E. Characterization of southern pine barks. Forest Prod. J. 19(8):23-30(1969).

16. Max, K. W. Chemical analysis of green loblolly pine. Southern Pulp Paper J. 7(8):36(1945).

17. Stanley, R. G. Extractives of wood, bark, and needles of the southern pines — a review. Forest Prod. J. 19(11):50-6(1969).

18. McGovern, J. N., and Chidester, G. H. Pulping loblolly pine heartwood with calcium-, magnesium-, and sodium-base sulphite liquors. Paper Trade J. 113(16):206-9(1941).

19. Byrd, V. L., Ellwood, E. L., Hitchings, R. G., and Barefoot, A. C. Wood characteristics and kraft paper properties of four selected loblolly pines. Part II: Wood chemical constituents and their relationship to fiber morphology. Forest Prod. J. 15(8):313-20(1965).

20. Blackford, J. M. Separating bark from wood chips. Forest Prod. J. 11(11): 515-19(1961).

21. Arola, R. A. Tremendous challenge remains — effective debarking of chips. Pulp Paper 44(1):79-83(1970).

22. Erickson, J. R. The status of methods for debarking wood chips. Tappi 55(8):1216-20(1972).

23. Arola, R. A., and Erickson, J. R. Compression debarking of wood chips. U.S.D.A. Forest Serv. Res. Paper NC-85, 1973. 11 p.

24. Harkin, J. M., and Crawford, D. M. Separation of wood and bark by gyratory screening. Forest Prod. J. 22(5):25-30(1972).

25. Sturos, J. A. Rotary screening to remove bark and foliage in the field. Northern Logger 21(11):16-17, 38(1973).

26. Robins, D. E. Beneficiation of wood-bark chip mixtures by the Cartesian-Diver principle. M.S. Thesis. Michigan Technological University, 1972.

27. Wesner, A. L. U.S. pat. 3,032,188(May 1, 1962).

28. Choong, E. T., and Fogg, P. J. Variation of moisture content in standing trees of southern pine species in southeast Louisiana. LSU Forestry Note No. 93, August 1970. 4 p.

29. Zobel, B., Matthias, M., Roberts, J. H., and Kellison, R. C. Moisture content of southern pine trees. North Carolina State Univ., School of Forest Resources, Tech. Rept. No. 37, Feb. 1968. 44 p.

30. McMillin, C. W. Mineral content of loblolly pinewood as related to specific gravity, growth rate, and distance from pith. Holzforschung 24(5):152-7(1970).

31. van Buijtenen, J. P. Anatomical factors influencing wood specific gravity of slash pines and the implications for the development of a high-quality pulpwood. Tappi 47(7):401-4(1964).

32. Einspahr, D. W., van Buijtenen, J. P., and Thode, E. F. Wood and pulp properties as determined from slash pine increment core and whole tree measurements. Silvae Genet. 11(3):68-77(1962).

33. Rydholm, S. A. Pulping processes. New York, Interscience Publishers, 1965. 1269 p.

34. Max, K. W. A study of tall oil from green and seasoned slash pinewood. Southern Pulp Paper J. 7(9):22-4, 26, 28(1945).

35. Squillace, A. E., and Gansel, C. R. Assessing the potential oleoresin yields of slash pine progenies at juvenile ages. U.S.D.A. Forest Service Note SE-95, 1968. 4 p.

36. Van Vliet, A. C. Converting bark into opportunities. Proc. of a conference held March 8-9, 1971, Oregon State Univ. 110 p.

37. Grillos, S. T., and Smith, F. H. The secondary phloem of Douglas-fir. Forest Sci. 5:377-88(1959).

38. Smith, J. H. G., and Kozak, A. Thickness, moisture content, and specific gravity of inner and outer bark of some Pacific northwest trees. Forest Prod. J. 21(2):38-40(1971).

39. Smith, J. H. G. Bases for sampling and simulation in studies of tree and stand weights. Forest Biomass Studies. XVth IUFRO Congress, University of Florida, Gainesville, Fla., March 15-20, 1971, p. 139-49.

40. Wilson, J. W., and Ifju, G. Wood characteristics. VII: Intra-increment relationship of Douglas-fir wood density, tensile strength and stiffness. Pulp and Paper Research Institute of Canada, Woodlands Research Index No. 170, August 1965. 24 p.

41. Brown, H. P., Panshin, A. J., and Forsaith, C. C. Textbook of wood technology. Vol. I: Structure, identification, defects, and uses of the commercial woods of the United States. New York, McGraw-Hill Book Company, Inc., 1st ed., 1949. 652 p.

42. Smith, D. A comparison of two methods for determining the specific gravity of small samples of second-growth Douglas-fir. U.S.D.A., Forest Products Lab. Rept. 2033, Sept. 1955. 13 p.

43. Cassens, D. L. Bark properties of eight western softwoods. Forest Prod. J. 24(4):40-5(1974).

44. Wilson, J. W., and Campbell, J. R. Wood characteristics. V: Wood zonal variations in Douglas-fir resinous extracts. Pulp and Paper Research Institute of Canada, Woodlands Research Index No. 169, July 1965. 14 p.

45. Campbell, J. R., Swan, E. P., and Wilson, J. W. Comparison of wood and growth zone resinous extracts in Douglas-fir. Pulp Paper Mag. Can. 66(4):T248-52(1965).

46. Chang, Y. P. Bark structure of North American conifers. U.S.D.A. Tech. Bull. No. 1095, Dec. 1954. 86 p.

47. Hall, J. A. Utilization of Douglas-fir bark. U.S.D.A., Forest Service, Pacific Northwest Forest and Range Expt. Sta., 1971. 138 p.

48. Hatton, J. V., and Keays, J. V. Complete-tree-utilization studies. III. Yield and quality of kraft pulp from the components of Pseudotsuga menziesii. Tappi 55(10):1505-8(1972).

49. Hillstrom, W. A. Chip debarking of several western species. U.S.D.A. Forest Serv. Res. Note No. NC-164, 1974. 4 p.

50. Maeglin, R. R., and Wahlgren, H. E. Western wood density survey, report no. 2. U.S.D.A. Forest Service Research Paper No. FPL 183, 1972. 24 p.

51. Worster, H. E., and Vinje, M. G. Kraft pulping of western hemlock tree tops and branches. Pulp Paper Mag. Can. 69:57-60(July 19, 1968).

52. Haas, B. R., and Kremers, R. E. Loosening bark from pulpwood with dilute acids. Tappi 47(11):726-8(1964).

GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

DBH. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Sclereid. See Sclerenchyma.

Schlerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

THE INSTITUTE OF PAPER CHEMISTRY

Marianne L. Harder
Research Assistant

John D. Hankey
Research Associate

Dean W. Einspahr
Senior Research Associate

John W. Swanson, Director
Division of Natural
Materials & Systems

APPENDIX

TABLE XXVI

SAMPLE TREE INFORMATION[a]

Species	Tree No.	Age, yr	Height, ft	DBH, inch	Location
Loblolly pine	3212-31	15	35	7.7	Alabama
	3212-32	15	35	7.6	Alabama
Slash pine	3212-36	Pulpwood bolt used			Alabama
	3212-37	Pulpwood bolt used			Alabama
Douglas-fir	3212-23	28	65	8.0	Washington
	3212-24	36	70	8.0	Washington
Western hemlock	3212-21	47	72	9.5	Washington
	3212-22	36	60	7.0	Washington

[a]Additional trees were sampled for wood/bark adhesion and bark strength measurements.

TABLE XXVII

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2	
	Peeling Season	Dormant Season
Loblolly pine	5.8	--[a]
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	3.5	9.1
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4

[a]It is estimated the dormant season value for loblolly pine would be similar to that of slash pine.

TABLE XXVIII

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm^2	
	Inner Bark	Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	7.4	--
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2[a]
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6

[a]Strength low, test samples failed during preparation, data based upon a single test.

IPST HASELTON LIBRARY
5 0602 01064699 2